Metropolitan District Commission
Division of Watershed Management

Water Quality Report: 2002
Wachusett Reservoir and Watershed

March 2003

ABSTRACT

The Metropolitan District Commission Division of Watershed Management was established by Chapter 372 of the Acts of 1984. The Division was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

Water quality sampling and watershed monitoring make up an important part of the overall mission of the Division. These activities are carried out by Environmental Quality Section staff at Wachusett Reservoir in West Boylston and at Quabbin Reservoir in Belchertown. This report is a summary of 2002 water quality data from the Wachusett watershed. A report summarizing 2002 water quality data from the Quabbin and Ware River watersheds is also available from the Division.

Acknowledgements:

This plan was prepared by the staff of the Metropolitan District Commission's Division of Watershed Management. Principal authors are Lawrence Pistrang, Aquatic Biologist, Wachusett/Sudbury Section and David Worden, Aquatic Biologist, Wachusett/Sudbury Section. Internal review was provided by John Scannell, Pat Austin, and David Getman. Frank Battista, John Tanona, David Worden, David Getman, and Lawrence Pistrang collected the samples and were responsible for all total and fecal coliform analysis.

MDC/DWM thanks the staff and management of the MWRA Deer Island Laboratory for preparing and delivering sample bottles and performing all nutrient analyses during the year.

Photographs on the cover of this report were taken from the MDC/DWM webpage at http://www.state.ma.us/mdc/.

All maps were produced by MDC/DWM GIS analyst Craig Fitzgerald, using the most recent MDC and MassGIS data.

WATER QUALITY REPORT: 2002
WACHUSETT RESERVOIR AND WATERSHED

1.0 INTRODUCTION

The Metropolitan District Commission Division of Watershed Management was established by Chapter 372 of the Acts of 1984. The Division was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

Water quality sampling and watershed monitoring make up an important part of the overall mission of the Division. These activities are carried out by Environmental Quality Section staff at Wachusett Reservoir in West Boylston and at Quabbin Reservoir in Belchertown. This report is a summary of 2002 water quality data from the Wachusett watershed. A report summarizing 2002 water quality data from the Quabbin and Ware River watersheds is also available from the Division.

The Surface Water Treatment Rule requires filtration of all surface water supplies unless several criteria are met, including the development and implementation of a detailed watershed protection plan. The Division and the MWRA currently have a joint waiver from the filtration requirement and continue to aggressively manage the watershed in order to maintain this waiver. Water quality sampling and field inspections help identify tributaries with water quality problems, aid in the implementation of the Division's watershed protection plan, and ensure compliance with state and federal water quality criteria for public drinking water supply sources. Bacterial monitoring of the reservoir and its tributaries provide an indication of sanitary quality and help to protect public health. The Division also samples to better understand the responses of the reservoir and its tributaries to a variety of physical, chemical, and biological inputs, and to assess the ecological health of the reservoir and the watershed.

Routine water quality samples were collected from twenty stations on fifteen tributaries and from five stations on the reservoir. Algal populations in the Wachusett Reservoir were monitored weekly at the Cosgrove Intake and quarterly at three additional stations in order to detect increasing concentrations (blooms) and potential taste and odor problems, and to recommend copper sulfate treatment when necessary. Fecal coliform samples were collected from the reservoir surface, documenting the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on both birds and bacteria concentrations.

All data collected were recorded in permanent laboratory books and also as part of an electronic database (Microsoft Excel files tribs-02.xls, Algae02.xls, and nutrients02.xls) located at the MDC-DWM Water Quality Laboratory in West Boylston, Massachusetts. Results of tributary and reservoir water quality testing are discussed by parameter in sections 3.1.1 – 4.4. All water quality data are included as appendices to this report.

The Pinecroft Area drainage basin is being investigated to evaluate the impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling established baseline and stormwater nutrient and bacteria levels and profiled water quality within a small urbanized subbasin at the headwaters of Gates Brook prior to sewer construction. Two additional sampling locations were added in 1997, one at an agricultural operation and one in a pristine forested watershed, enabling the Division to compare and contrast urbanized conditions with those from agricultural and pristine sites.

Weekly sampling of the Pinecroft neighborhood continued in 2002 following the installation of sewers. Weekly samples were also collected from the agricultural and pristine sampling stations when flow was present. Data collected as part of this study are included in this report. Over four hundred homes have been connected to sewers in this neighborhood and water quality in the subbasin is expected to improve dramatically. A complete analysis will be published separately after one more year of data collection and interpretation.

Environmental Quality staff continued to monitor site-specific impacts of development on water quality. Ongoing communications with state and local officials helped ensure implementation of best management practices, remediation of existing problems, and quick notification of imminent threats. Staff attempted to communicate with conservation commission and board of health members on a regular basis to provide technical assistance and to gain advance knowledge of proposed activities. All investigations and projects were documented as part of a revised and comprehensive filing system.

In an effort to refine the process of threat assessment within the Wachusett watershed, Environmental Quality staff divided the watershed into five sanitary districts with the goal of completing a detailed assessment of one district per year on a five-year rotating basis. Information was gathered on hydrology, natural resources, demographics, land use, historic water quality, and both actual and potential threats for the six subbasins within the Thomas Basin District (tributaries discharging into the reservoir upgradient of the Route 12 Bridge). The information was reviewed and summarized in a district overview during 2002, with detailed information presented in six individual subbasin chapters. Both general and specific recommendations are being developed along with a proposed timeline for actions, and the Thomas Basin District Environmental Quality Assessment will be published under separate cover early in 2003.

2.0 DESCRIPTION OF WATERSHED MONITORING PROGRAM

Wachusett Environmental Quality staff collected routine water quality samples from twenty stations on fifteen tributaries and from five stations on the reservoir during 2002. The stations are described below in Table 1 and are located on Figure 1. Additional stations were sampled intermittently to support special studies or potential enforcement actions. Nearly 5,500 samples were analyzed in-house; approximately 5,000 bacteria samples, almost 300 algae samples, and more than 100 chemical samples. Almost 2,000 physiochemical measurements were done in the field. In addition, forty-two samples were collected and sent to the MWRA Deer Island laboratory for almost 1000 analyses of nutrients and metals.

Each tributary station was visited weekly throughout the year. Temperature and conductivity were measured in the field using a Corning CD-30 conductivity meter and samples were collected for total and fecal coliform analysis. All analyses were done at the MDC lab facility in John Augustus Hall in West Boylston. Samples for nitrate-nitrogen, nitrite-nitrogen, ammonia, silica, total phosphorus, UV-254, total suspended solids, and total organic carbon were collected in April and November from eleven stations and analyzed at the MWRA Deer Island Lab. Monthly samples for nutrients and metals were collected from the Quinapoxet and Stillwater Rivers and sent to the MWRA as well. Depth measurements were done at these stations to calculate flow using previously established rating curves. All sample collections and analyses were conducted according to Standard Methods for the Examination of Water and Wastewater 20th Ed. (Table 2).

Monthly temperature, dissolved oxygen, pH, and conductivity profiles were taken at three reservoir stations (Station 3417/Basin North, Station 3412/Basin South, and Thomas Basin) using a Hydrolab Surveyor III. Quarterly samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, silica, alkalinity, and total phosphorus were collected at the same three stations plus the Cosgrove Intake from the epilimnion, metalimnion, and hypolimnion during thermal stratification and at two depths (surface and bottom) during isothermal conditions. All parameters were analyzed by the MWRA Lab at Deer Island.

Total and fecal coliform samples were collected daily (Monday - Thursday) from the surface at the Cosgrove Intake and from the Route 12 Bridge at Thomas Basin to ensure compliance with federal regulations and to help monitor the effect of weather conditions, tributary inputs, and migratory gull and geese populations on bacteria concentrations. Total and fecal coliform samples were also collected monthly or biweekly at numerous locations on the reservoir surface, documenting the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on both birds and bacteria concentrations. A sampling grid established nine years earlier with twenty-three sampling locations based on reservoir configuration and flow paths was again utilized. An additional sampling location near the dam was added in anticipation of withdrawals through the Wachusett Aqueduct in 2003. Several samples were also collected at depth to investigate differences in vertical contamination. Sample locations are indicated on Figure 2.

TABLE 1

2002 WACHUSETT SAMPLING STATIONS

STATION	LOCATION	FREQUENCY
1. Boylston Brook	Route 70, Boylston	W
2. Cook Brook (Wyoming)	Wyoming Street, Holden	W, Q
3. French Brook (70)	Route 70, Boylston	W, Q
4. Gates Brook (1)	Gate 25, W.Boylston	W, Q
5. Gates Brook (2)	Route 140, W.Boylston	W
6. Gates Brook (3)	Worcester Street, W.Boylston	W
7. Gates Brook (4)	Pierce Street, W.Boylston	W
8. Gates Brook (6)	Lombard Avenue, W.Boylston	W
9. Gates Brook (9)	Woodland Street, W.Boylston	W
10. Jordan Farm Brook	Route 68, Rutland	W, Q
11. Hastings Cove Brook	Route 70, Boylston	W
12. Malagasco Brook	West Temple Street, Boylston	W, Q
13. Malden Brook	Thomas Street, W.Boylston	W, Q
14. Muddy Brook	Route 140, W.Boylston	W, Q
15. Quabbin Aqueduct	below circular dam, W.Boylston	W
16. Quinapoxet River	Canada Mills, Holden	W, Q, *
17. Rocky Brook (East Branch)	Rowley Hill Road, Sterling	W, Q
18. Stillwater River (sb)	Muddy Pond Road, Sterling	W, Q, *
19. Waushacum Brook (Pr)	Prescott Street, W.Boylston	W
20. West Boylston Brook	Gate 25, W.Boylston	W, Q
A. 3409 (Reservoir)	Cosgrove Intake	D, W, M
B. 3417 (Reservoir)	mid reservoir by Cunningham Ledge	M, Q
C. 3412 (Reservoir)	mid reservoir southwest of narrows	M, Q
D. TB (Reservoir)	Thomas Basin	M, Q
E. Route 12 Bridge	north side of Route 12 (Thomas Basin)	D

D = daily (bacteria Monday – Thursday)
W = weekly (bacteria, temperature, conductivity [tributaries] and algae [Cosgrove])
M = monthly (reservoir profiles)
Q = quarterly (algae [reservoir] and nutrients)
* = monthly for nutrients and metals

Figure 1.

SAMPLING STATIONS

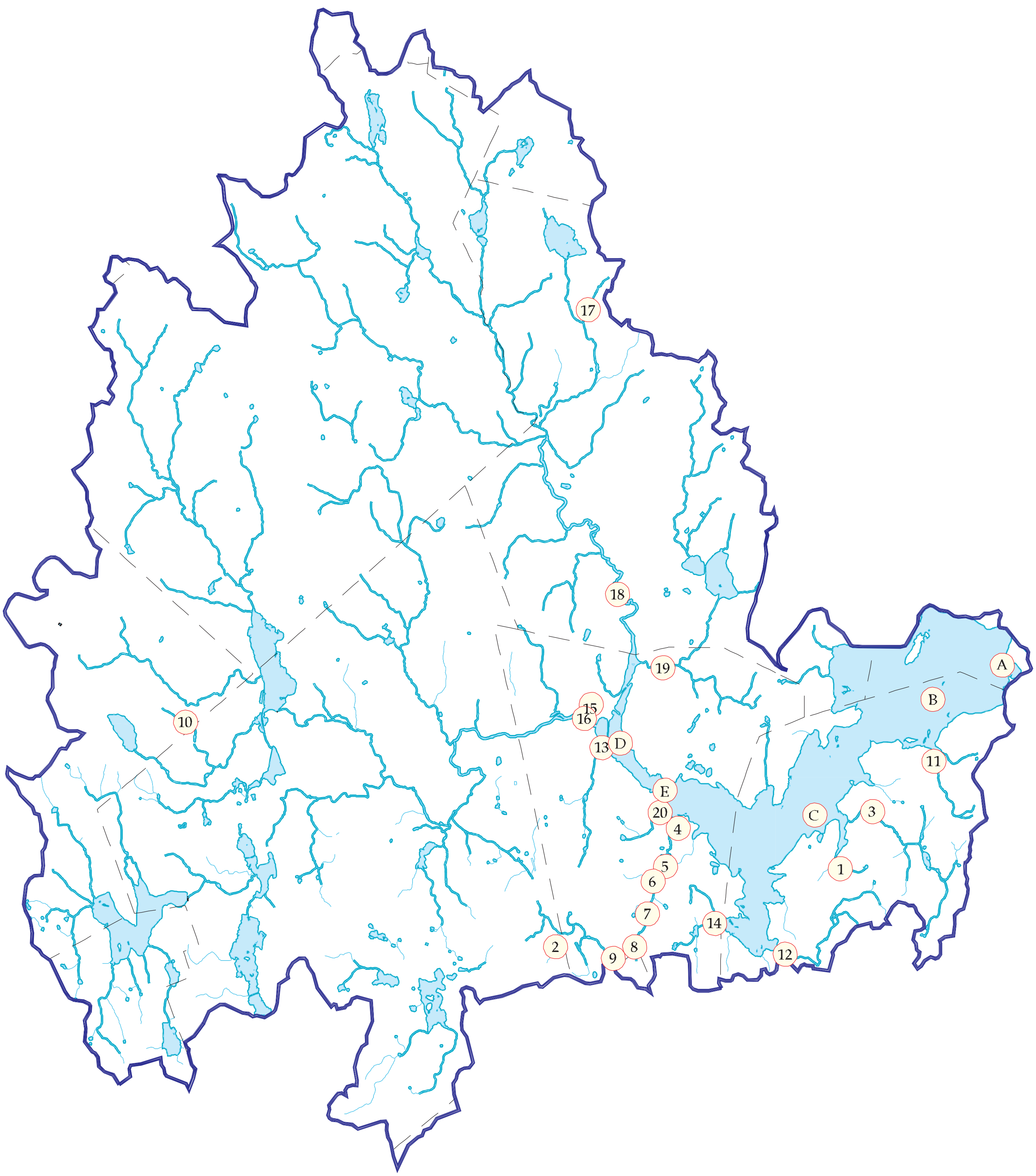


Figure 2.

RESERVOIR TRANSECT STATIONS

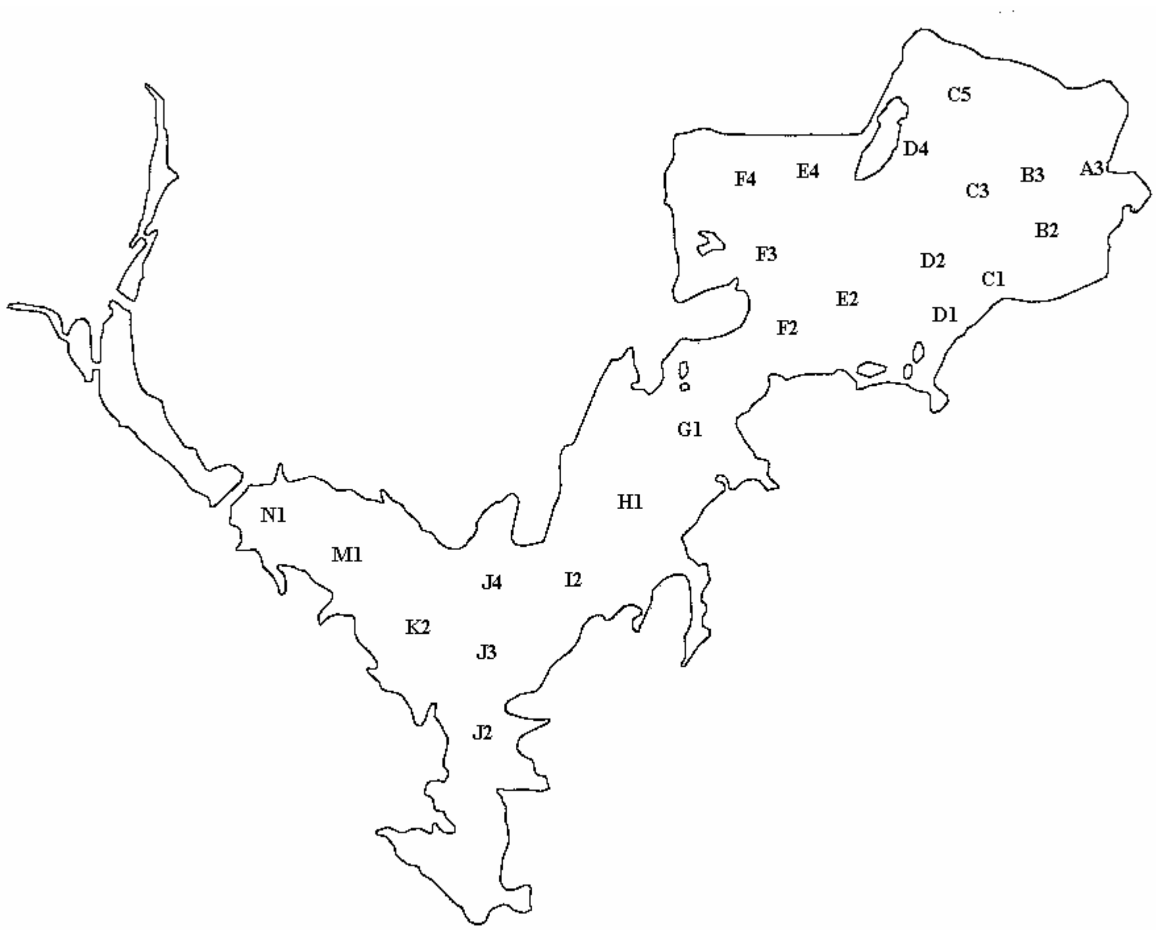


TABLE 2

METHODS USED FOR FIELD AND LABORATORY ANALYSIS
WACHUSETT LABORATORY

PARAMETER	STANDARD METHOD
pH	Hydrolab Surveyor III
Conductivity	YSI Model 30 meter Hydrolab Surveyor III
Temperature	Hydrolab Surveyor III YSI Model 30 meter
Dissolved Oxygen	Hydrolab Surveyor III
Total Coliform	SM 9222 B
Fecal Coliform	SM 9222 D
Algae	SM 10200 F

SM = Standard Methods for the Examination of Water and Wastewater - 20th edition, 1999

Algal populations in the Wachusett Reservoir were monitored at the Cosgrove Intake to detect increasing levels (blooms) and potential taste and odor problems, and to recommend copper sulfate treatment when necessary. Samples were collected weekly at six depths (0, 6, 8, 10, 12, and 14m) to help detect rapidly changing populations of golden-brown algae and other potential problem genera. Samples were collected quarterly from three additional stations to help improve the Division's understanding of algal population dynamics throughout the entire reservoir.

Routine macrophyte (rooted aquatic plant) surveys of Wachusett Reservoir were initiated by MDC staff in 1999. Detection of alien species and characterization of the reservoir macrophyte community are the main goals of survey efforts. Surveys consist of visual observations and mapping of littoral zone vegetation from a boat. Each survey effort generally focuses on a discrete shoreline area and is often performed in conjunction with other field activities involving boat operation. Observations of macrophytes growing at depth are aided by the use of a view box. Specimens are collected with a rake or grab when needed to facilitate plant identification. A preliminary database on the composition and distribution of the Wachusett Reservoir macrophyte community, assembled from multiple surveys conducted since 1999, is presented for the first time in this report.

3.0 RESULTS OF TRIBUTARY MONITORING PROGRAM

3.1 BACTERIA

Total and fecal coliform were measured as an indicator of sanitary quality. Coliform density has been established as a significant measure of the degree of pollution and has been used as a basis of standards for bacteriological quality of water supplies for some time. Total coliform are defined in Standard Methods for the Examination of Water and Wastewater - 20th edition (1999) as “facultative anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria that develop red colonies with a metallic golden sheen within 24 hours at 35° C on an Endo-type medium containing lactose”. Fecal coliform are a subset of total coliform bacteria that produce blue colonies on M-FC media when incubated for 24 hours at 44.5° C. Fecal coliform bacteria are found within the digestive system of warm-blooded animals and are almost always present in water containing pathogens. Both groups of bacteria are relatively easy to isolate in a laboratory, and direct counts can be made using membrane filtration. The presence of any coliform bacteria in drinking water suggests that there may be disease-causing agents in the water.

Total and fecal coliform levels were measured weekly at all tributary stations. The Massachusetts Class A surface water quality standards established in 314 CMR 4.00 state that “fecal coliform bacteria shall not exceed an arithmetic mean of 20 colonies per 100 mL in any representative set of samples, nor shall more than 10% of the samples exceed 100 colonies per 100 mL”. Using a yearly arithmetic mean, the standard of 20 colonies per 100 mL was exceeded at seventeen of twenty tributary stations (85%). Only Jordan Farm Brook, Rocky Brook (East Branch), and the Quabbin Aqueduct had an annual average of less than the standard. This is an improvement over the results from 2001, but is not representative of the water quality improvements hoped for by the Division and it is clear that additional remedial efforts are needed to reduce fecal contamination.

One or two high values can markedly elevate the annual mean of a relatively small data set, and fecal coliform values often increase by several orders of magnitude following storm events or during periods of high groundwater. An alternate way of looking at summary data may give a better representation of actual conditions in these tributaries throughout the year. The use of median values to represent water quality was proposed several years ago by Environmental Quality staff. Table 3 includes both annual mean and annual median values for fecal coliform data in the tributaries.

Median fecal coliform concentrations in 2002 were generally lower than those measured in 2001. Eight stations (Cook, Jordan Farm, Malden, Stillwater, West Boylston, and Gates 1, 4, and 6) showed some improvement, while only four (French, Quinapoxet, Gates 3, and Waushacum) had slightly higher median concentrations. Three of the stations with improved water quality (Cook, Gates 6, and Jordan Farm) had significantly lower values than the previous year, and three (Gates 1, Jordan Farm, and Malden) recorded their lowest median concentration ever. It should also be noted that only 6 of 20 stations (30%) recorded annual median fecal coliform concentrations of more than 20 colonies per 100 mL. Eight of these same stations had annual median values that exceeded 20 colonies per 100 mL in 2001, and nine had higher median values in 2000.

TABLE 3

FECAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN (2002)	MEDIAN (2001)	SAMPLES
Boylston Brook	340	<10	43	10	10	35
Cook Bk. (Wyoming)	3000	<10	109	20	50	43
French Brook (70)	240	<10	32	10	<10	39
Gates Brook (1)	2000	<10	69	10*	20	49
Gates Brook (2)	2000	<10	158	50	50	49
Gates Brook (3)	2000	<10	141	40	30	49
Gates Brook (4)	2000	<10	130	50	60	49
Gates Brook (6)	2000	<10	206	50	115	49
Gates Brook (9)	1200	<10	89	20	20	49
Hastings Cove Brook	140	<10	24	<10	<10	36
Jordan Farm Brook	300	<10	18*	<10*	25	31
Malagasco Brook	780	<10	77	20	20	49
Malden Brook	280	<10	30	10*	20	49
Muddy Brook	560	<10	39	10	10	49
Quabbin Aqueduct	2	0	0	0	0	28
Quinapoxet River	1500	<10	101	40	20	49
Rocky Bk. (E. Branch)	60	0	5	<10	<10	32
Stillwater River (sb)	460	<10	70	20	25	49
Waushacum Brook (Pr)	1010	<10	53	20	10	49
West Boylston Brook	2000	<10	166	40	50	49

*below historic levels

Samples collected at 12 of 20 sampling stations (60%) exceeded the Class A standard of “no more than 10% of the samples shall exceed 100 colonies per 100 mL.” Although additional improvements are still desirable, this also was better than the previous year. The winter and spring of 2002 were extremely dry and storm events were virtually nonexistent. Unlike the previous year when a lack of rainfall during the summer and fall led to low flows and concentration of contaminants, the absence of early season rain events in 2002 appears to have helped reduce the amount of bacteria reaching the streams via stormwater flow. New municipal sewers in the towns of Holden and West Boylston may also have provided benefits, although many homes have not yet connected to the system.

When the tributaries are ranked using annual mean values, stations on Gates Brook have four of the five highest concentrations of fecal coliform. West Boylston Brook also is one of the worst, with an annual mean better only than Gates 6 (Lombard Avenue). Cook Brook (Wyoming), the Quinapoxet River, and Gates 9 (Woodland Street) complete the list of the eight worst stations. Using median values instead of mean values reduces the impact of storm events and often changes tributary rankings, but when 2002 tributaries are ranked using median values instead of means there is very little difference. This is not usually the case; with few significant storms in 2002, the rankings based on mean values and median values were very similar.

The list of tributaries with the poorest water quality as represented by fecal coliform concentrations was similar to the 2001 list, although there were some notable exceptions. Cook Brook was the worst in 2001; sewer connections in the headwater neighborhood appear to have improved water quality. The Quinapoxet River showed a dramatic decline in water quality.

TABLE 4

TOTAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN	SAMPLES
Boylston Brook	2400	20	457	200	35
Cook Bk. (Wyoming)	15,000	<10	805	160	43
French Brook (70)	3,900	<10	317	100	39
Gates Brook (1)	20,000	10	661	120	49
Gates Brook (2)	20,000	50	1536	330	49
Gates Brook (3)	20,000	30	1201	365	49
Gates Brook (4)	20,000	10	1306	650	49
Gates Brook (6)	20,000	20	1786	205	49
Gates Brook (9)	15,000	<10	829	180	49
Hastings Cove Brook	1660	<10	287	125	36
Jordan Farm Brook	180	<10	51	30	31
Malagasco Brook	4000	<10	514	280	49
Malden Brook	2100	<10	320	135	49
Muddy Brook	2640	10	431	225	49
Quabbin Aqueduct	34	0	10	5	28
Quinapoxet River	7800	10	524	230	49
Rocky Bk. (E. Branch)	560	4	43	16	32
Stillwater River (sb)	1400	<10	347	205	49
Waushacum Brook (Pr)	4400	<10	322	145	49
West Boylston Brook	20,000	10	1458	325	49

Massachusetts Class A surface water quality standards do not currently address total coliform bacteria, but staff have historically used 100 colonies per 100 mL as a general guideline to indicate whether or not a tributary or the reservoir is seriously contaminated. The presence of a single coliform colony in a finished drinking water sample is indicative of a problem. The EPA has established a legal limit that states no more than five percent of monthly drinking water samples from a water system can contain coliform. Source water containing less than 100 total coliform colonies per 100 mL should not contain any coliform following standard treatment procedures or filtration. Using a yearly arithmetic mean, the Division's standard of 100 colonies per 100 mL was exceeded at seventeen of twenty tributary stations (see Table 4). As with the fecal coliform data, only Jordan Farm Brook, Rocky Brook (East Branch), and the Quabbin Aqueduct had an annual average of less than the standard. High concentrations were recorded following storm events and during low flow conditions in the summer, and mean values of these relatively small data sets were dramatically impacted by these samples. The use of median values as an alternative method to represent water quality has been considered by Environmental Quality staff. Table 4 includes both annual mean and annual median values for fecal coliform data in the tributaries.

When annual median total coliform values are used, the same seventeen stations exceed the standard of 100 total coliform colonies per 100 mL. Total coliform appears to be present in the Wachusett tributaries at elevated concentrations throughout much of the year, especially in developed subbasins and following storm events. It is also apparent that total coliform data are consistent with fecal coliform data collected at the same time from the same stations, so routine analysis of total coliform bacteria will not be done in the future. This will provide extra lab time for added fecal analysis at special stations and during additional storm events.

Multiple sampling stations on Gates Brook are traditionally examined to help locate sources of fecal contamination. Gates Brook remains one of the most contaminated tributaries in the watershed, although once the new municipal sewers are connected to individual homes it is expected that water quality will dramatically improve. The results from the six stations were variable, although it was clear in 2002 that conditions at Gates 6 remain worse than at the other stations. Gates 6 had the highest annual mean values for both total and fecal coliform. Many of the homes along the tributary between Gates 2 and Gates 9 have recently been connected to the sewer system, and 2003 water quality data from these sampling stations should be much improved.

Historical data were examined to detect any long-term water quality trends. Most of the sampling stations had below normal annual median fecal coliform concentrations, possibly due to a below-average number of storm events as well as improvements to wastewater treatment. The Stillwater River and Waushacum Brook had concentrations similar to previous years; the Quinapoxet River had concentrations twice the norm. It is not clear why water quality declined in the Quinapoxet River, but an Environmental Quality Assessment of this subbasin is scheduled for 2003 and sources of contamination will be addressed.

3.2 NUTRIENTS

Samples for nitrate-nitrogen, nitrite-nitrogen, ammonia, total phosphorus, silica, UV-254, total suspended solids, and total organic carbon were collected in April and November from eleven stations and analyzed at the MWRA Deer Island Lab. Monthly samples for the same parameters plus twenty-one metals were collected from the Quinapoxet and Stillwater Rivers and sent to the MWRA as well. Samples for nitrate-nitrogen, nitrite-nitrogen, and ammonia were filtered in the field using a 1 micron glass fiber Acrodisc and then frozen; samples for total phosphorus were frozen without filtration. Samples for the other parameters were preserved as necessary according to standard methods. Flow measurements were determined each week using staff gages and USGS rating curves. Samples were delivered regularly to the MWRA lab at Deer Island and analyzed using methods with low detection limits. All data collected are included in an appendix to this report and are discussed in the following section.

Nitrate-nitrogen concentrations measured in the eight routine tributaries (excluding the "Pinecroft Study" stations) ranged from 0.017 mg/L NO_3-N to 2.18 mg/L NO_3-N. Nitrate levels have historically been highest in West Boylston Brook and are usually significantly elevated with respect to the other tributaries and the reservoir. This was true once again in 2002. The mean annual nitrate-nitrogen concentration in West Boylston Brook was between five and twenty-five times higher than those measured in all other tributaries with the exception of Gates Brook. Elevated nitrate levels in these two brooks are expected because of the high number of improperly functioning septic systems and the density of development in these subbasins.

TABLE 5

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.186	0.285	0.089	1.62	2.18	0.297	0.617	0.641
MIN	0.017	0.204	0.064	1.48	1.72	0.172	0.209	0.090
MEAN							0.427	0.239

Concentrations were higher at the Cook Brook station than in any other sampled during the year, with a maximum value of 4.63 mg/L NO_3-N and an annual mean concentration more than double than what was seen in West Boylston Brook. Samples collected from Jordan Farm Brook had concentrations comparable to those seen in West Boylston and Gates Brook samples. Nitrate-nitrogen was detected only at very low concentrations in samples from Rocky Brook (East Branch).

Nitrate data from the three "Pinecroft study" streams continue to illustrate significant differences based on different land uses (Table 6). Concentrations were highest in samples from the stream in a high density residential watershed with on-site wastewater treatment. Concentrations in Cook Brook were more than double those recorded from Jordan Farm Brook, which has a watershed dominated by agricultural land use. Samples from Rocky Brook (East Branch) contained very low concentrations of nitrate-nitrogen. This tributary is in a forested watershed with almost no development at all.

TABLE 6

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

STATION	COOK (Wyoming)	JORDAN FARM	ROCKY (East)
LANDUSE	[residential]	[agriculture]	[undeveloped]
MAX	4.63	1.86	0.035
MIN	4.39	1.77	<0.005

Nitrate-nitrogen concentrations observed during 2002 were within historic ranges in all tributaries, and most were significantly lower than the previous year, although sampling was done only twice at most stations rather than monthly as in previous years. The three "Pinecroft study" streams had concentrations comparable to those recorded during 2001. Concentrations were generally higher in November than in April with the exception of the three "Pinecroft study" streams and the Quinapoxet River.

Nitrite-nitrogen was detected at very low concentrations, with a maximum recorded value of 0.012 mg/L measured in April at Cook Brook. Most samples, including all samples from French, Malagasco, Muddy, Gates, West Boylston, Malden, Jordan Farm and Rocky Brooks had concentrations below the limits of detection (0.005 mg/L). Only nine of forty samples (including both samples from Cook Brook, four of eleven samples from the Quinapoxet River, and three of eleven samples from the Stillwater River) contained detectable concentrations of nitrite-nitrogen.

Ammonia was detected at slightly higher concentrations, especially in Cook Brook and in the Stillwater and Quinapoxet Rivers. Concentrations were lower than in the previous two years at all stations except Cook Brook.

TABLE 7

AMMONIA-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAG	MUDDY	GATES	W.BOYL	MALDEN	QUIN	STILL	COOK	JFARM	ROCKY
MAX	0.014	0.013	0.017	0.016	0.014	0.009	0.052	0.029	0.068	0.006	0.006
MIN	0.010	0.007	0.008	0.008	<0.005	<0.005	0.009	<0.005	0.017	<0.005	<0.005
MEAN							0.022	0.013			

Phosphorus is an important nutrient, and has been determined to be the limiting factor controlling algal productivity in the Wachusett Reservoir. EPA Water Quality Criteria (1976) recommended a maximum concentration of 0.05 mg/L total phosphorus in tributary streams in order to prevent accelerated eutrophication of receiving waterbodies. Concentrations measured in the Wachusett tributaries ranged from 0.007 mg/L to 0.212 mg/L total P during 2002. Concentrations were much lower than in previous years in all tributaries except the Quinapoxet River (although considerably fewer samples were collected), with only four of forty-two samples collected exceeding the recommended concentration. All elevated total phosphorus concentrations were measured in the Stillwater and Quinapoxet Rivers. This was similar to what was observed in 2000, when most of the smaller tributaries had low measured phosphorus values but the two large rivers had elevated readings. Concentrations in the smaller streams were elevated during 2001 when both precipitation and stream flows were below average.

TABLE 8

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.027	0.034	0.045	0.035	0.019	0.020	0.212	0.104
MIN	0.017	0.023	0.019	0.029	0.018	0.019	0.015	0.013
MEAN							0.046	0.034

Data from the three Pinecroft tributaries (Table 9) illustrate differences caused by land use, with total phosphorus concentrations in Cook Brook (residential) twice those measured in Jordan Farm Brook (agriculture) and in Rocky Brook (undeveloped). Total phosphorus in all three tributaries was less than in 2001 and comparable to that seen in the smaller tributaries.

TABLE 9

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

STATION	COOK (Wyoming)	JORDAN FARM	ROCKY (East)
LANDUSE	[residential]	[agriculture]	[undeveloped]
MAX	0.031	0.014	0.017
MIN	0.021	0.007	0.007

Silica concentrations ranged from a low of 3.90 mg/L (5/21) to a high of 11.2 mg/L (3/19). Both extremes were recorded from the Quinapoxet River. The annual mean concentration in the watershed during 2002 was 7.30 mg/L. Concentrations were remarkably similar throughout the watershed. Cook Brook had the highest annual mean concentration, while French Brook again had the lowest. Low concentrations were measured in the Quinapoxet River and Malagasco Brook as well.

Total suspended solids are those particles suspended in a water sample retained by a filter of 2μm pore size. These particles can be naturally occurring or might be the result of human activities. Total suspended solids in the Wachusett tributaries ranged from <1 to 69.5 mg/L, with most samples containing less than 5 mg/L. High suspended solids were measured during November in Muddy Brook and during April, May, and November in the Stillwater River. All other samples contained less than 10 mg/L.

Total organic carbon (TOC) and UV-254 measure organic constituents in water and are important as a way to predict precursors of harmful disinfection byproducts. TOC in the tributaries ranged from 1.97 to 21.8 mg/L, with an overall mean value of 5.84 mg/L. The highest readings were recorded from Malagasco, French, and Muddy Brooks. Measurements of UV-254 were comparable to TOC measurements as expected. Organic compounds such as tannins and humic substances absorb UV radiation and there is a correlation between UV absorption and organic carbon content. The highest UV-254 readings were also from Malagasco and French Brooks.

Concentrations of twenty-one metals were measured in samples collected from the Stillwater and Quinapoxet Rivers each month. No antimony, beryllium, selenium, silver, or thallium were detected in any samples, and arsenic, cadmium, copper, chromium, lead, mercury, and nickel were present at very low concentrations (less than 10 μg/L). Barium (41.5 μg/L) and zinc (26.8 μg/L) were present in slightly higher concentrations. Aluminum, calcium, iron, magnesium, manganese, potassium, and sodium were all seen at higher concentrations (see Table 9a). The only significant difference between the two rivers appears to be in the amount of sodium present; concentrations in the Quinapoxet were more than twice the concentration measured in the Stillwater.

TABLE 9a

METALS CONCENTRATIONS (mg/L) – annual mean and range

station	Al	Ca	Fe	Mg	Mn	K	Na
QUINAPOXET	0.25	9.51	0.53	1.79	0.13	2.03	37.8
range	1.54 - 0.08	12.1 - 6.72	2.57 - 0.21	2.22 - 1.23	0.63 - 0.03	2.48 - 1.49	50.6 - 21.9
STILLWATER	0.27	8.06	0.55	1.43	0.11	1.59	17.1
range	0.65 - 0.06	14.8 - 4.19	1.26 - 0.13	2.42 - 0.86	0.25 - 0.04	2.49 - 0.98	24.8 - 11.8

3.3 SPECIFIC CONDUCTANCE

Fresh water systems almost always contain small to moderate amounts of mineral salts in solution. Specific conductance is a measure of the ability of water to carry an electric current, which is dependent on the concentration and availability of these ions. Elevated conductivity levels are indicative of contamination from stormwater or failing septic systems, or can be the result of watershed soil types.

Criteria were proposed by the DWM during the mid 1990s relating conductivity and fecal coliform levels to the likelihood of contamination from failing septic systems. A simple statistical analysis was used to develop a ranking system for tributaries, using percent exceedence of specific criteria. Tributaries with more than fifty percent of the samples exceeding the Class A Standard for fecal coliform of twenty colonies per 100 mL are considered impacted by septic systems. The impact is considered minor if less than eighty percent of samples exceed a specific conductance standard of 120 μmhos/cm, moderate if greater than eighty percent of samples exceed the 120 μmhos/cm standard, and severe if more than twenty percent of samples exceed a standard of 360 μmhos/cm. These criteria appear to give a fairly good indication of whether or not a sampling location is impacted by failing septic systems rather than by an alternative source of contamination, although annual flow conditions need to be considered. Stream flow appears to be directly related to conductivity, with “dry” years (low flows) concentrating contaminants during the warm months and elevating mean annual conductivity. Years with less precipitation and lower tributary flow result in higher overall conductivity measurements and appear to increase the number of streams severely impacted. For this reason it is suggested that more than a single year be used in assessing these criteria.

Specific conductance was measured weekly at all stations with a low of 33 μmhos/cm at Jordan Farm Brook and a high of 4707 μmhos/cm at Gates Brook (Woodland Street). Annual mean ranged from 52 μmhos/cm (Rocky Brook) to 1069 μmhos/cm (Gates Brook at Lombard Avenue). The highest values were seen during winter and spring and were related to snow and ice storms, salt applications, and elevated runoff. Unlike most years when conductivity values were higher in the summer, fall, and early winter when flows were low, measurements in most tributaries during 2002 were remarkably uniform.

An assessment of specific conductance and fecal coliform data from 2002 using the criteria described above found that only six of twenty stations were likely contaminated by improperly functioning septic systems. All six stations (West Boylston Brook, the Quinapoxet River, and four stations on Gates Brook) were considered severely impaired. Problems along Gates and West Boylston Brooks have been well documented, and sewers have been constructed specifically to deal with this issue. A station on Cook Brook previously determined to be impacted by inadequate septic systems no longer was considered “likely contaminated”, with water quality improvements probably the result of numerous connections to the new sewer. The Quinapoxet River has never previously been identified as likely contaminated until this year, although it was close to meeting the criteria in 2001. A decline in water quality in the Quinapoxet River has been discussed in previous sections of this report; a detailed investigation will be done in 2003 to determine the reason for the decline.

A five-year examination of this assessment (1998 through 2002) seems to indicate improving conditions in the watershed. Only thirty percent of the assessed tributaries were deemed likely contaminated by faulty septic systems, down from 33% in 2000, 38% in 1999, and 47% in 1998. A similar number were reported in 2001. Continued improvement is expected, with reductions in fecal coliform concentrations and specific conductance over the next few years as many of the remaining homes with outdated or failing septic systems are connected to new municipal sewers in West Boylston and Holden.

3.4 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity, or the measure of a solution's acidity or alkalinity, is expressed as pH on a scale ranging from 0 to 14. Underlying geologic formations, biological processes, and human contaminants impact the pH of a water body. In this region most streams and lakes tend to be relatively acidic (pH less than 7) due to granite bedrock and the impact of acid precipitation originating from the Midwest.

No measurements of pH have been done for the past three years. More than a decade of routine sampling in the tributaries has shown very little variation either seasonally or over time. Historic low values in some tributaries may have been caused by impacts of runoff from acid precipitation, while all other recorded values are considered to be representative of normal background conditions.

3.5 *GIARDIA / CRYPTOSPORIDIUM*

Giardia and *Cryptosporidium* samples were not collected by Environmental Quality staff during 2002. Data have been collected from a number of locations over the past several years, but no clear seasonal trends have been determined, and presence or absence appear to be related more to precipitation, flow conditions, and presence of wildlife rather than season. Sampling will continue under the auspices of a UMASS study to help improve our understanding of the presence of these protozoa.

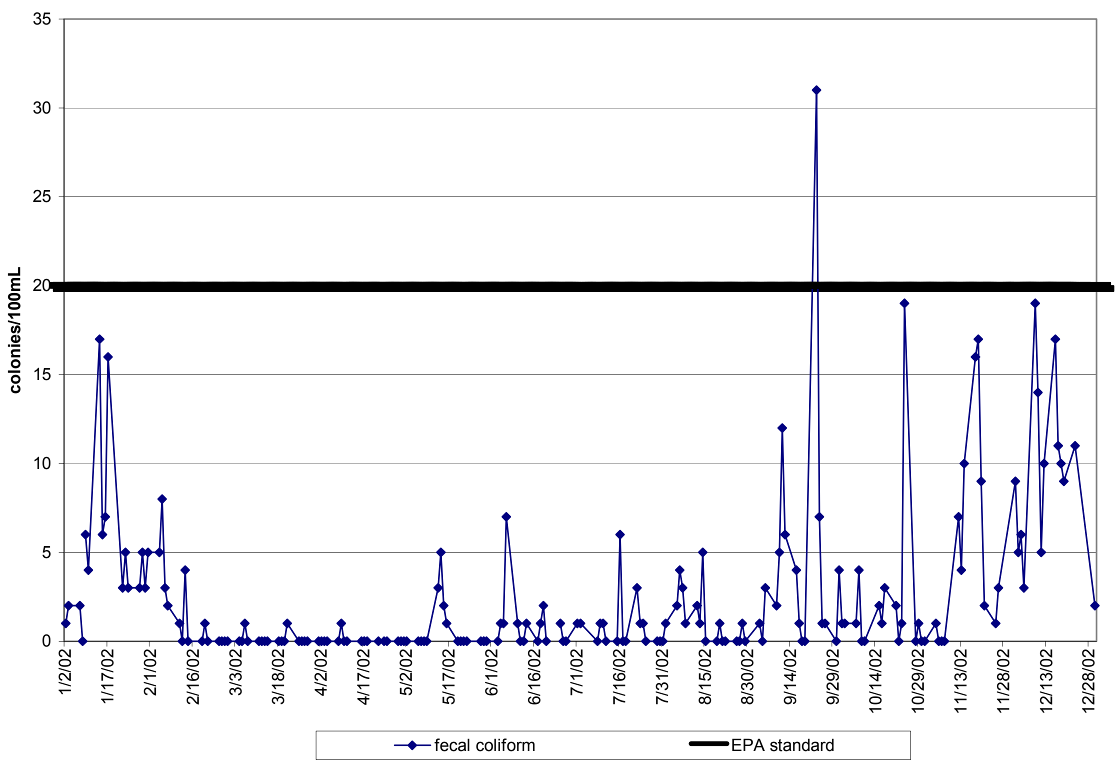
4.0 RESULTS OF RESERVOIR MONITORING PROGRAM

4.1 BACTERIA

A total of 193 bacteria samples were collected at the Cosgrove Intake by Environmental Quality staff during 2002. All but one were surface samples collected from the back walkway; a single sample in January was taken from an internal tap when ice formation around the intake structure precluded sampling by the usual method. EPA's fecal coliform criteria for drinking water require that at least ninety percent of all source water samples contain less than 20 colonies per 100 mL. More than ninety-nine percent of the samples collected at the Cosgrove Intake during 2002 contained less than the standard (Figure 6). The standard was exceeded only once, on September 23rd following a steady rain. Problems caused by roosting gulls and other waterfowl were minimized due to a rigorous harassment program and bacteria levels remained below the standard during the critical winter months. MWRA official compliance samples are always collected from the internal tap and did not exceed the standard at any time during 2002.

FIGURE 3

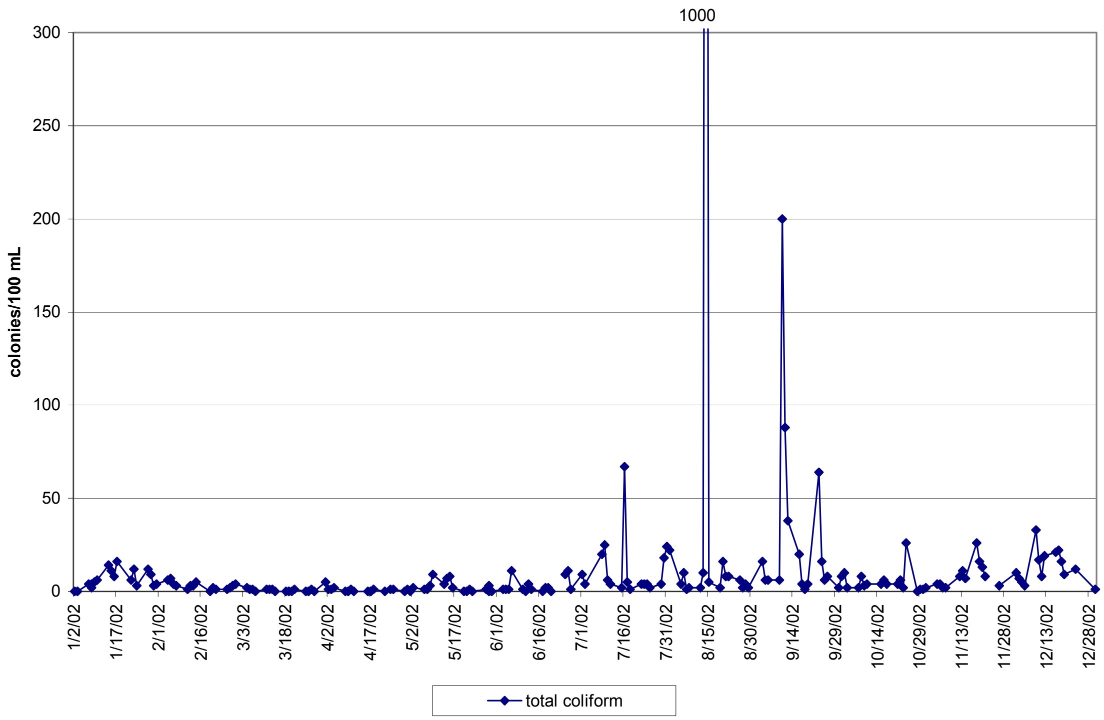
COSGROVE INTAKE
FECAL COLIFORM CONCENTRATIONS (colonies/100mL)



Total coliform was measured in all samples collected from the Cosgrove Intake during 2002. Concentrations were low during much of the year with periodic elevated levels during the summer. No matching rise in fecal coliform concentrations was seen. Total coliform concentrations were lower than in the previous year, without the three month period of consistently elevated concentrations seen during the summer of 2001.

FIGURE 4

COSGROVE INTAKE
TOTAL COLIFORM CONCENTRATIONS (colonies/100mL)



Bacteria samples were also collected at twenty-three surface stations across the reservoir and from 5, 10, and 20 meters deep at one station to document the relationship between seasonal bacteria variations and roosting populations of gulls and geese. Samples were also collected at two depths near the Clinton dam in preparation for future withdrawals through the Wachusett Aqueduct. Sample locations were illustrated on Figure 2. Samples were collected weekly, biweekly, or monthly throughout the year. No sampling dates were missed due to ice cover for the first time in fifteen years. All total and fecal coliform data are included in Tables 10 and 11 on the following pages.

Table 10
Fecal Coliform Transect Data

fecal col	01/16/02	01/23/02	01/30/02	02/06/02	02/13/02	02/20/02	03/06/02	03/28/02	04/17/02	05/29/02	06/26/02	07/17/02	08/22/02	09/18/02	10/09/02	10/24/02	11/25/02	12/11/02	12/23/02
Cosgrove	7	5	3	3	4	1	1	0	0	0	0	0	0	0	0	19	1	5	11
B-2	12	12	4	2	8	1	1	0	19	0	0	1	0	0	0	1	5	3	14
B-3	4	10	6	6	6	1	1	0	0	0	0	0	0	0	0	1	2	14	14
C-1	10	4	1	2	4	1	1	0	10	0	0	0	1	0	0	0	1	6	17
C-3	7	2	4	4	10	2	1	0	0	0	0	0	0	1	2	2	9	26	10
C-5	6	1	2	1	8	1	1	0	0	1	0	0	0	7	0	0	2	32	14
D-1	31	8	6	8	2	1	1	1	3	3	0	0	1	0	2	3	4	11	7
D-2	58	4	6	14	4	6	1	0	0	0	0	0	0	0	1	3	9	23	10
D-2 (5m)	44	18	8	2		4					1		2	0	2	7			
D-2 (10m)	55	34	8	10		1					0		1	1	1	2	6	18	
D-2 (20m)	60	n/a	12	8		1					0		1	1	4	12			
D-4	5	22	8	1	8	1	1	0	5	0	0	0	0	1	0	3	5	41	9
E-2	51	24	30	1	4	1	1	0	0	0	0	0	5	0	62	3	19	33	16
E-4	12	14	2	4	1	1	1	0	0	0	0	0	1	1	0	2	5	54	8
F-2	17	18	24	1	4	1	1	0	0	1	0	0	1	2	2	1	7	14	14
F-3	81	24	34	4	2	4	1	0	0	0	0	3	0	0	0	2	5	36	4
F-4	28	4	32	20	6	1	1	0	0	0	1	0	2	0	0	1	4	22	8
G-2	14	8	4	1	8	1	1	0	1	0	0	0	0	0	0	1	7	31	12
H-2	10	12	4	150	12	316	1	2	8	0	0	0	1	0	0	2	2	20	37
I-2	41	16	22	100	30	10	68	10	62	5	0	0	0	2	5	3	24	44	52
J-2	4	4	2	40	6	4	1	3	0	1	0	1		2	0	2	1	14	66
J-3	116	98	174	38	140	8	16	57	12	5	0	0	3	1	21	12	22	127	58
J-4	110	194	28	48	84	10	64	14	1	0	1	0	1	0	22	41	25	112	218
K-2	167	134	40		128	16	36	23	0	6	0	0	1	0	1	20	61	160+	130
M-1	21	36	12		50	28	2	3	2	4	0	3	1	12	0	3	14	23	91
N-1	5		1		30	14	7	0	0	1	0	0	0	0	0	6	18	11	73
dam (0m)														1	0	1	1	9	10
dam (10m)														0	2	1	0	14	

Table 11
Total Coliform Transect Data

total col	01/16/02	01/23/02	01/30/02	02/06/02	02/13/02	02/20/02	03/06/02	03/28/02	04/17/02	05/29/02	06/26/02	07/17/02	08/22/02	09/18/02	10/09/02	10/24/02	11/25/02	12/11/02	12/23/02
Cosgrove	8	12	3	4	3	2	1	0	0	0	11	5	8	1	3	26		8	12
B-2	14	12	10	2	4	1	1	0	20	2	29	2	49	1	7	8		10	16
B-3	10	10	4	10	6	2	1	1	0	0	24	1	37	0	12	2		14	17
C-1	11	12	1	1	1	1	1	0	12	0	22	0	14	0	5	3		7	18
C-3	14	4	6	2	10	1	1	1	5	0	23	1	2	7	2	6		28	10
C-5	5	6	4	2	16	1	2	0	0	0	20	0	4	24	2	0		41	15
D-1	35	28	6	4	2	1	1	1	3	3	36	1	49	1	5	4		12	9
D-2	60	12	10	18	2	10	1	0	0	0	28	1	50	0	5	3		26	11
D-2 (5m)	58	20	10	6		4					74		3	6	6	8			
D-2 (10m)	56	44	10	6		1					11		2	8	12	5		19	
D-2 (20m)	61	n/a	10	8		1					3		1	5	4	24			
D-4	12	22	8	6	12	1	1	1	5	0	21	1	5	3	4	4		43	10
E-2	58	24	36	1	2	1	6	0	0	1	34	0	8	2	67	6		33	15
E-4	36	18	1	1	2	1	2	0	0	0	21	0	4	10	16	4		59	9
F-2	19	16	24	6	4	1	2	0	1	2	17	3	3	3	4	2		16	16
F-3	85	12	66	2	2	2	1	0	0	1	3	5	1	3	9	9		39	5
F-4	36	18	24	22	6	1	1	0	0	0	8	0	2	2	2	1		29	14
G-2	20	12	2	8	8	6	1	1	6	1	114	0	5	1	2	2		32	17
H-2	26	18	8	178	20	576	2	2	10	0	67	2	2	1	0	3		21	40
I-2	56	28	34	128	38	18	72	11	65	7	86	1	3	3	10	7		49	65
J-2	3	2	2	48	22	1	6	4	0	3	60	2		3	3	3		18	69
J-3	120	154	178	52	182	8	28	59	12	4	16	0	3	1	36	21		136	84
J-4	174	210	64	79	90	18	94	21	2	0	115	1	1	0	27	63		128	228
K-2	230	146	86		142	24	46	32	1	3	127	0	2	1	2	25		174+	136
M-1	26	44	14		58	28	8	4	25	12	3	4	1	21	11	11		39	142
N-1	4		4		68	16	8	7	4	4	83	0	2	1	33	8		15	82
dam (0m)														14	7	1		14	12
dam (10m)														0	5	2		23	

Samples collected in January contained elevated concentrations of fecal coliform through much of the reservoir, with numbers highest at mid reservoir (D-1, D-2, E-2), Prescott Cove (F-3, F-4), the narrows (F-2), and near the south (J-3, J-4, K-2) and east (I-2) roosts. February and March samples contained very low concentrations of fecal coliform at most stations, but high numbers continued to be recorded from stations near the south and east roosts. Fecal coliform concentrations were very low during April, May, June, July, August, and September; only 52 of 149 samples contained any fecal coliform, and only five from scattered locations (B-2, C-1, I-2, J-3, M-1) contained 10 or more colonies per 100 mL.

Concentrations were still low in early October, with single samples from mid reservoir (E-2) and two from the south roost (J-3, J-4) containing elevated levels of fecal coliform. Bird numbers were very low in comparison to previous years, and this was reflected by the low levels of bacteria. Slightly higher concentrations were recorded at the end of October, but numbers were still considerably lower than usual.

Samples collected in November contained slightly more fecal coliform than in October, but concentrations were still much lower than expected. Bacteria were highest in areas that were used by roosting gulls and other waterfowl. The number of birds using the reservoir began to increase during November, and by December concentrations of fecal coliform were elevated at all locations. Samples at 15 of 26 stations contained 20 or more colonies per 100 mL on December 11th, although samples collected at or near the Cosgrove Intake still contained very few fecal coliform bacteria. Concentrations were still high at the end of the month, although a smaller number of samples exceeded the Class A standard of 20 colonies per 100 mL.

Fecal coliform concentrations did not exceed 100 colonies per 100 mL in any sample collected from the north end of the reservoir during 2002. Sixteen samples at the south end of the reservoir did contain 100 or more colonies, all during December, January, and February, and all associated with large populations of roosting gulls. The average of all transect samples collected in 2002 was thirteen fecal coliform colonies per 100mL; the annual median was only two colonies per 100mL.

Total coliform concentrations were similar to fecal coliform concentrations, with only a few significant differences noted. Very low concentrations of fecal coliform at all sampling stations were recorded in June, but all samples contained elevated concentrations of total coliform (see Table 11 above). Similar results were noted in samples from the north end of th reservoir in August. On all other sampling dates the total coliform and fecal coliform concentrations were almost identical. Previous studies have suggested that *Aeromonas* sp. could be present in high concentrations during the summer and this organism could have been responsible for the elevated total coliform levels.

The bird harassment program was very successful in 2002, with fewer gulls, geese, and ducks visiting the north end of the reservoir until late in the season and no exceedence of the fecal coliform standard. It appears that many birds have adapted their flight patterns to avoid the north end of the reservoir entirely. A detailed summary of the harassment program with associated data is published weekly throughout the harassment season as part of the MWRA Weekly Water Quality Report.

4.2 WATER COLUMN CHARACTERISTICS

4.2.1 FIELD PROCEDURE

MDC staff routinely measure water column profiles in the Wachusett Reservoir for the following parameters: temperature, dissolved oxygen, percent oxygen saturation, specific conductance, and hydrogen ion activity (pH). Profiles are measured monthly at the three main stations (Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin; see Figure 1) weather and ice conditions permitting.

The frequency of profile measurement is increased to semimonthly or weekly during the summer period of thermal stratification in order to monitor growth conditions for phytoplankton and to track the progress of the Quabbin "interflow" through the Wachusett basin during periods of water transfer. The thermally stratified water column of summer is characterized by a layer of warm, less dense water occupying the top of the water column ("epilimnion"), a stratum with a thermal gradient in the middle ("metalimnion"), and a stratum of cold, dense water at the bottom ("hypolimnion"). Profiles are also measured at additional locations of interest including the Route 12 Bridge, the Quinapoxet Basin railroad bridge, the Beaman Street Bridge, and the Stillwater Basin railroad bridge during the stratification period. Profiles are measured at one meter intervals, except during periods of isothermy and mixing (generally November through March) when intervals of two or three meters are adequate to characterize the water column.

Water column profiles are measured with a "Reporter" or "H20" multiprobe and "Surveyor 3" water quality logging system manufactured by Hydrolab Corporation (Austin, Texas). This instrument is generally charged and calibrated on the day preceding each field effort and also given a post-measurement calibration check. At the conclusion of field work, data recorded by the logging system are downloaded to a PC and transformed into an EXCEL spreadsheet.

Station 3417 (Basin North) has been selected for graphically depicting seasonal changes in the water column profile of Wachusett Reservoir because it is representative of the deepest portion of the basin and it is not influenced by turbulence from local water inputs or withdrawals that could disrupt profile characteristics. Profiles measured in Thomas Basin and at Cosgrove Intake (Station 3409) are influenced by inflow from the Quabbin Aqueduct and withdrawal at the Cosgrove Intake respectively.

4.2.2 THE QUABBIN "INTERFLOW" IN WACHUSETT RESERVOIR

The transfer of water from Quabbin to Wachusett Reservoir via the Quabbin Aqueduct has a profound influence on the water budget, profile characteristics, and hydrodynamics of the Wachusett Reservoir. During the years 1995 through 2002, the amount of water transferred annually from Quabbin to Wachusett ranged from a volume equivalent to 44 percent of the Wachusett basin up to 94 percent. The period of peak transfer rates generally occurs from June through November. However, at any time of the year, approximately half of the water in the Wachusett basin is derived from Quabbin Reservoir.

The peak transfer period overlaps the period of thermal stratification in Wachusett and Quabbin Reservoirs. Water entering the Quabbin Aqueduct at Shaft 12 is withdrawn from depths of 13 to 23 meters in Quabbin Reservoir. These depths are within the hypolimnion of Quabbin Reservoir where water temperatures range from only 9 to 13 degrees C in the period June through October. This deep withdrawal from Quabbin is colder and denser relative to epilimnetic waters in Wachusett Reservoir. However, due to a slight gain in heat from mixing as it passes through Quinapoxet Basin and Thomas Basin, the transfer water is not as cold and dense as the hypolimnion of Wachusett. Therefore, Quabbin water transferred during the period of thermal stratification flows conformably into the metalimnion of Wachusett where water temperatures and densities coincide.

The term interflow describes this metalimnetic flow path for the Quabbin transfer that generally forms between depths of 7 to 15 meters in the Wachusett water column. The interflow penetrates through the main basin of Wachusett Reservoir (from the Route 12 Bridge to Cosgrove Intake) in about 3 to 6 weeks depending on the timing and intensity of transfer from Quabbin. The interflow essentially connects Quabbin inflow to Cosgrove Intake in a "short circuit" undergoing minimal mixing with ambient Wachusett Reservoir water.

A sustained transfer was initiated on June 13th and continued through November 18th, except for a brief cessation of transfer during the final five days of September. A weak conductivity minimum was detected in front of Cosgrove Intake on July 17th (see Specific Conductance section below) indicating completion of interflow penetration through the main basin in a period of 34 days. By mid-August, the interflow stratum had developed into its typical configuration with a thickness of eight meters forming between 6 and 14 meters deep. At the conclusion of 2002, the transfer volume totaled 229 million cubic meters, equivalent to 91 percent of the Wachusett basin volume. The influence of the 2002 Quabbin interflow on profile characteristics in Wachusett Reservoir is discussed in the sections that follow.

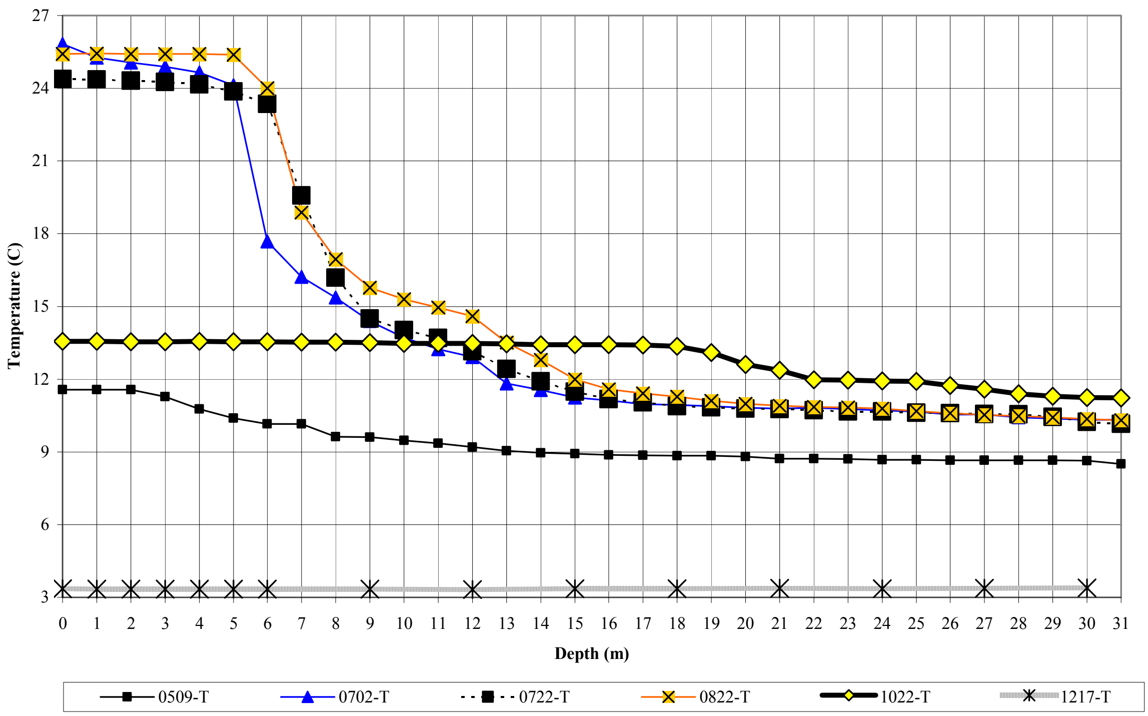
4.2.3 TEMPERATURE

Typical of most deep lakes and reservoirs in the temperate region, Wachusett Reservoir becomes thermally stratified in summer. The development of thermal stratification due to solar radiation and atmospheric warming in spring and summer and the subsequent loss of heat leading to fall turnover at Station 3417 (Basin North) is depicted in Figure 5.

The initial stages of thermal stratification were evident on May 9th when a difference of approximately three degrees C existed between the top and bottom of the water column (Figure 5). The top of the water column continued to gain heat and the upper five meters had reached a temperature of approximately 25 degrees C by July 2nd. Differences in water density resulting from the thermal gradient caused the typical stratification pattern of epilimnion, metalimnion, and hypolimnion to form in the water column.

FIGURE 5

Wachusett Reservoir Temperature Profiles
Basin North/Station 3417



The development of the interflow from Quabbin (see Interflow section above) can been seen in the profile measured on July 22nd. A very steep thermal gradient exists between depths of six and eight meters in which the temperature dropped approximately eight degrees C. Profiles measured in late July and August show a thermocline (defined as a temperature gradient of 1 degree C per meter or greater) beginning at a depth of 6 meters and falling steeply to temperatures characteristic of the Quabbin interflow. This steep gradient in temperature and density caused by the interflow stabilized the position of the metalimnion between depths of approximately 6 and 14 meters.

The presence of the Quabbin interflow was also evident in the temperature profiles as a minor bump or plateau in the thermocline between 9 and 12 meters where the temperature centers around 13 to 14 degrees C (Figure 5). This plateau represents the "core" of the interflow stratum that undergoes minimal mixing with ambient Wachusett water.

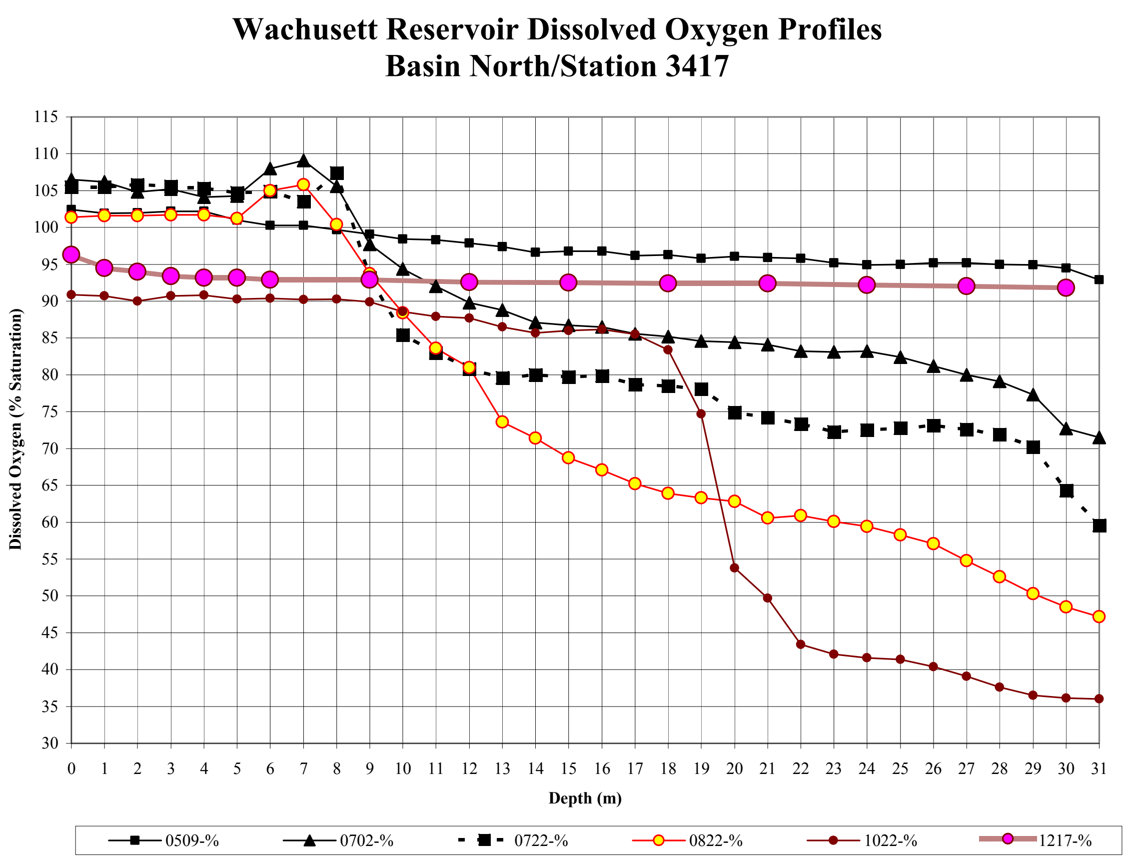
Highest temperatures in the epilimnion were recorded in July and August at about 25 degrees C while temperatures in the hypolimnion remained at about 10 degrees C throughout the summer (Figure 5). This thermal gradient persisted through the end of August. In September, the system began to lose heat as air temperatures cooled.

Profiles measured on October 22nd show that heat losses and wind energy had caused the water column to be mixed down to a depth of 18 meters thus homogenizing the epilimnion and the metalimnetic Quabbin interflow. A difference of less than 3 degrees C existed between the top and bottom of the water column at this time (Figure 5). Soon after the October 22nd measurement date, wind energy dispersed the remnant stratification pattern and mixed the entire water column, in an event known as fall "turnover". Profiles recorded on December 17th show the water column to be isothermal at slightly over 3 degrees C (Figure 5).

4.2.4 DISSOLVED OXYGEN

Measurement of dissolved oxygen profiles throughout most of the year generally show values ranging from 70 to 100 percent saturation for ambient water temperatures. A maximum dissolved oxygen saturation value of 109% was observed in the upper portion of the metalimnion at a depth of 7 meters on the July 2nd measurement date (Figure 6). The sharp thermal gradient at this depth in combination with other factors evidently triggered intense photosynthetic activity by phytoplankton concentrated in this narrow vertical stratum. The release of oxygen associated with this activity resulted in the spike of high saturation values measured on this date. Similar, but less pronounced spikes in dissolved oxygen profiles were also observed later in July and in August.

FIGURE 6



During the period of thermal stratification, demand for oxygen in the hypolimnion reduced oxygen concentrations to as low as 36 percent saturation before fall turnover in early November replenished oxygen throughout the water column. Reductions in oxygen concentration are also evident in the metalimnion during the stratification period, but these are mainly indicative of oxygen demand within the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir. The progressive lowering of dissolved oxygen saturation values in the metalimnion and hypolimnion from May through October at Station 3417 (Basin North) is depicted in Figure 6.

On July 22nd hypolimnetic dissolved oxygen concentrations were around 75 percent saturation except for the very bottom of the water column which was at 60 percent saturation. By August 22nd, hypolimnetic concentrations at most depths had declined into the 55 to 65 percent saturation range with concentrations less than 50 percent recorded near the bottom of the water column (Figure 6). Relatively low saturation values measured near the bottom of the water column indicate slightly higher rates of oxygen demand by microbial decomposition processes occurring at the sediment-water interface.

Hypolimnetic oxygen concentrations in September and October continued to decline gradually into the 45 to 55 percent saturation range. Profiles measured on October 22nd show that heat losses and wind energy had caused the water column to be mixed to a depth of 18 meters with a concomitant replenishment of oxygen to more than 80 percent saturation throughout the mixed volume. Also on this date, in the remaining intact hypolimnion, a brief period of low oxygen values was observed with percent saturation values ranging from 36 to 43 percent in the bottom ten meters of the water column. Absolute dissolved oxygen concentrations in this volume of water fell to below 5 ppm which occurs infrequently in the reservoir being last observed in late October of 1998.

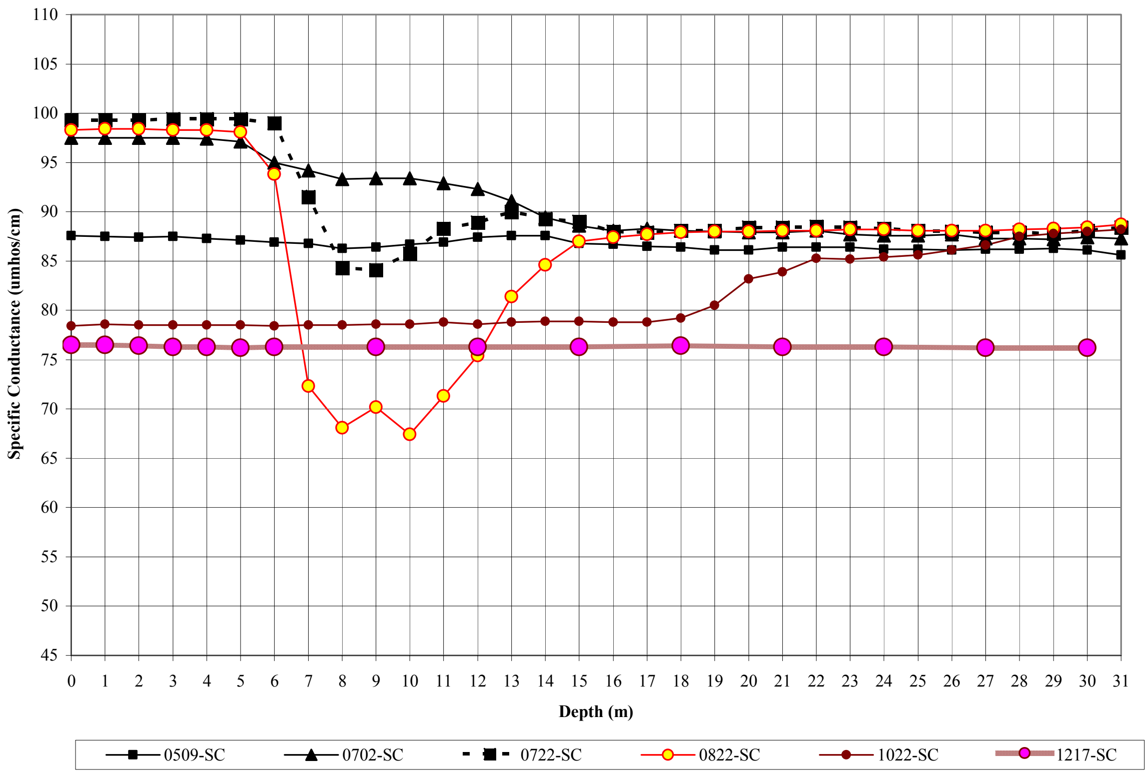
Soon after the October 22nd measurement date, wind energy dispersed the remnant stratification pattern, mixing and exposing the entire basin volume to the atmosphere and replenishing dissolved oxygen concentrations at all depths. December 17th profiles show dissolved oxygen between 92 and 95 percent saturation at all depths (Figure 6).

4.2.5 SPECIFIC CONDUCTANCE

Specific conductance (“conductivity”) profiles in Wachusett Reservoir reflect the interplay between native water contributed from the Wachusett watershed and water transferred from Quabbin. The Quinapoxet and Stillwater Rivers are the main tributaries to Wachusett Reservoir and account for approximately 75 percent of annual inflow from the reservoir watershed. Measurements of conductivity in these rivers generally range from between 60 and 240 µmhos/cm with an average value between 125 and 150 µmhos/cm. In contrast, the average conductivity value of Quabbin water is about 40 µmhos/cm. Typically during periods of isothermy and mixing (November through March), conductivity values throughout the main Wachusett basin range from 75 to 100 µmhos/cm depending on the amount of water received from Quabbin. During the summer stratification period the Quabbin interflow is conspicuous in profile measurements as a metalimnetic stratum of low conductivity. Figure 7 depicts conductivity profiles measured at Station 3417 (Basin North) from May through December.

FIGURE 7

Wachusett Reservoir Conductivity Profiles
Basin North/Station 3417



On May 9th, before the Quabbin transfer had been initiated, conductivity values ranged between 86 and 88 μmhos/cm throughout the water column. The profiles recorded from July 2nd through August 22nd show the development of the interflow stratum as a "trough" in the conductivity profile between depths of 6 and 14 meters (Figure 7). This trough intensifies (extends to lower conductivity values) over the period of transfer as water in the interior of the interflow undergoes less mixing with ambient reservoir water at the boundaries of the interflow stratum. On August 22nd, a minimum interflow conductivity value of 67.4 μmhos/cm was observed at a depth of 10 meters at Station 3417.

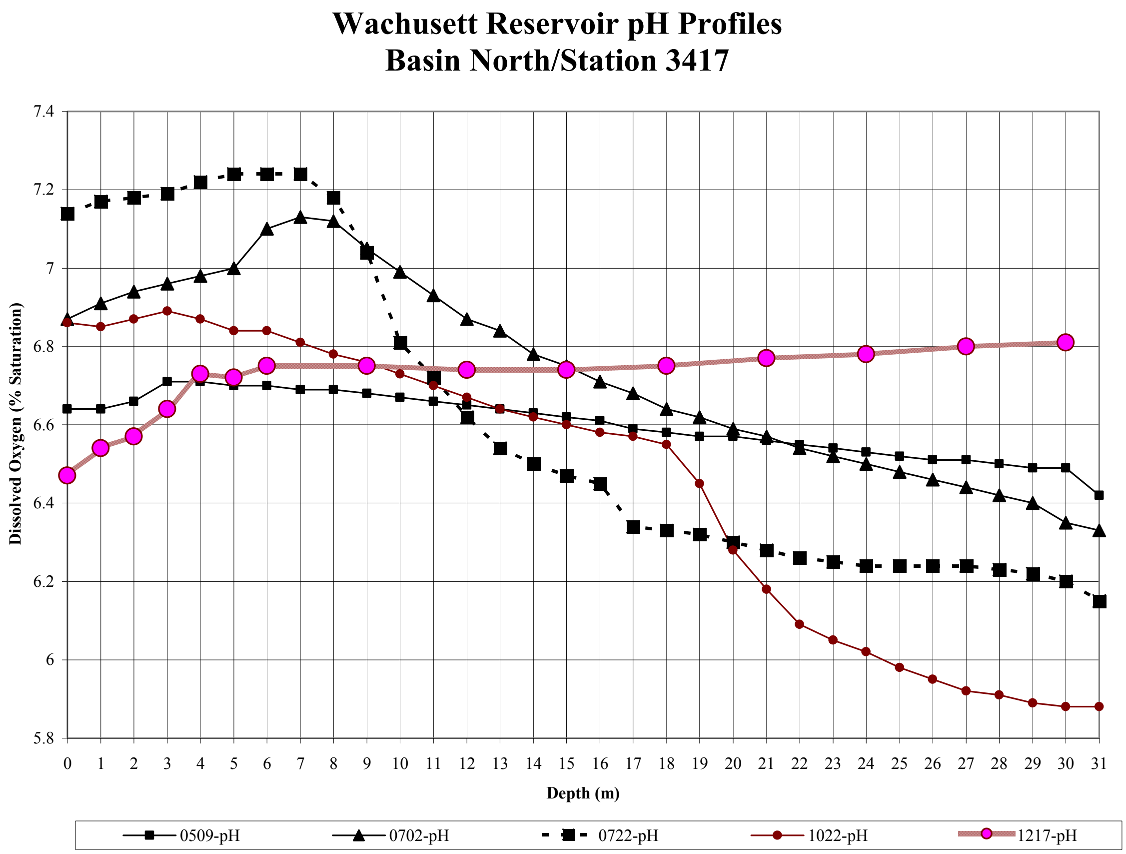
Profiles measured on October 22nd show that heat losses and wind energy had caused the water column to be mixed down to a depth of 18 meters. The conductivity of the stratum resulting from the homogenization of the epilimnion and metalimnetic Quabbin interflow was approximately 79 μmhos/cm. A slight gradient of increasing conductivity persisted below 18 meters (Figure 7). Soon after the October 22nd measurement date, wind energy dispersed the remnant stratification pattern and mixed the entire water column. By December 17th, with the Quabbin transfer continuing to dilute the Wachusett water column, a conductivity value of approximately 76 μmhos/cm was measured uniformly throughout.

4.2.6 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity (pH) in Wachusett Reservoir is determined ultimately by the exchange of inorganic carbon between the atmosphere and water (the carbon dioxide-bicarbonate-carbonate "buffering system"). Specific patterns of pH distribution vertically in the water column and seasonally over the year are mainly determined by the opposing processes of photosynthesis and respiration. Generally, pH values in Wachusett Reservoir range from around neutral (pH=7) to slightly acidic (pH=6). Figure 8 depicts pH profiles measured at Station 3417 (Basin North) from May through December.

Photosynthesis by phytoplankton results in the uptake of carbon dioxide dissolved in the water. The uptake of carbon dioxide tends to increase pH in the epilimnion where photosynthetic activity is greatest. Maximum pH values around 7.2 were observed around the boundary between epilimnion and metalimnion at depths of 4 to 7 meters on the July 22nd measurement date (Figure 8). As discussed above in relation to the dissolved oxygen maximum, a short period of intense photosynthetic activity by phytoplankton concentrated at this depth was evidently triggered by the sharp thermal gradient in combination with other factors. A similar, but less pronounced maximum in pH was also associated with high dissolved oxygen concentrations recorded earlier on the July 2nd measurement date.

FIGURE 8



Photosynthetic activity maintained epilimnetic pH in the range between 6.6 and 6.9 through July. Values of pH ranging from 6.4 to 6.8 were measured in the metalimnion during the stratification period, but these are mainly indicative of the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir.

In contrast to the utilization of carbon dioxide by photosynthetic organisms, microbial decomposition of organic matter produces carbon dioxide. In the hypolimnion, where microbial respiration is the dominant process, the production of carbon dioxide tends to decrease pH. By July 22nd, pH values in the hypolimnion had decreased to values around 6.2. Hypolimnetic pH values continued to decrease to a minimum of around 5.9 by late October. Wind energy dispersed the stratification pattern at turnover with resulting pH values between 6.5 and 6.8 measured uniformly throughout the mixed water column in December (Figure 8).

4.3 NUTRIENTS

4.3.1 FIELD PROCEDURE

Sampling for measurement of nutrient concentrations in Wachusett Reservoir has been conducted quarterly since the conclusion of the program of monthly sampling conducted from October 1998 to September 1999. Quarterly sampling was conducted at the onset of thermal stratification (late April - early May), in the middle of the stratification period (late July), near the end of the stratification period (late October - early November), and during a winter period of mixis before ice cover (December). Samples were collected at three of the main stations used in the 1998-99 year of study (Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin; see Figure 1).

Samples were collected in the epilimnion, metalimnion, and hypolimnion during the period of thermal stratification and near the top, middle, and bottom of the water column during mixis. Water column profiles of temperature, dissolved oxygen, and other parameters measured with a multiprobe were evaluated in the field to determine depths for metalimnetic samples.

Quarterly sampling continued to be performed in collaboration with MWRA staff at the Deer Island Central Laboratory who provided sample containers and where all grab samples were sent for analysis. Sampling protocol, chain-of-custody documentation, and sample delivery were similar to those established in the 1998-99 year of study. Details of sampling protocol are provided the Water Quality Report: 1999 - Wachusett Reservoir and Watershed (MDC/DWM, 1999). Modifications to the quarterly sampling program have consisted only of a lower minimum detection limit for total Kjeldahl-nitrogen (reduced to 0.2 mg/L from 0.6 mg/L) and the addition of UV254 absorbance among the parameters to be measured. Measurement of UV absorbance at a wavelength of approximately 254 nanometers serves as is a relative assay of the concentrations of organic compounds dissolved in the water.

4.3.2 RESULTS OF NUTRIENT ANALYSES

The nutrient database for Wachusett Reservoir established in the 1998-99 year of monthly sampling and subsequent quarterly sampling through 2001 is used as a basis for interpreting data generated in 2002. Consistent with patterns and trends in data documented since 1999, the Quabbin transfer is evident as the dominant influence on Wachusett Reservoir nutrient concentrations in 2002. Results of quarterly nutrient sampling in 2002 document concentrations that generally register at the low end of the historical ranges (Table 12). In particular, silica and UV absorbance were measured at concentrations and intensities below the minimum values observed to date. The low nutrient concentrations recorded in 2002 reflect the linkage of Wachusett Reservoir to Quabbin Reservoir as described in the paragraphs that follow.

Nutrient concentrations in Wachusett Reservoir are influenced by a variety of factors that fluctuate annually including amounts of runoff discharged from the watershed (rain and snowmelt), nutrient loading rates associated with the runoff, and population dynamics of phytoplankton. Overriding these factors however, is the timing and duration of the Quabbin transfer. Water quality within the reservoir basin reflects a dynamic interaction between the influences of the Wachusett watershed and the Quabbin transfer. The Quabbin transfer is characterized by water of very low nutrient concentrations whereas the influence of the Wachusett watershed is exerted mostly via the discharges of the Quinapoxet and Stillwater Rivers with higher nutrient concentrations.

The interplay between these two influences results in slight shifts in the range of nutrient concentrations from one year to the next. The year 2002 was exceptional in that transfer occurred each and every month albeit sporadically in the months of March, April, and May. Historically, the peak period of transfer from Quabbin consists of July, August, and September each year, with usually no transfers during February, March, or April. However, by April of 2002, the cumulative volume of water transferred from Quabbin amounted to a record high 64.4 million cubic meters, equivalent to 26 percent of the Wachusett basin volume. A sustained transfer was initiated on June 13th and continued through November 18th (except for a brief cessation of transfer during the last five days of September). By October of 2002, the cumulative volume of water transferred from Quabbin amounted to a record high 208 million cubic meters or 83 percent of the Wachusett basin volume. In a year such as 2002, with transfer occurring throughout the year and mostly continuously, nutrient concentrations will be lower due to the early entry and greater proportion of Quabbin derived water occupying the basin. At the conclusion of 2002, the transfer volume totaled 229 million cubic meters, equivalent to 91 percent of the Wachusett basin volume.

Conversely, in years with delayed or reduced inputs from Quabbin or higher amounts of local precipitation or snowmelt, nutrient concentrations will range higher as discharges from the Quinapoxet and Stillwater Rivers have greater proportional influence. This was evident in 2000 when the Quabbin transfer was not initiated until June 28th and nutrient concentrations were generally highest in samples collected in May of that year. Similarly, in 2001, an exceptionally wet spring intensified nutrient loading from the Quinapoxet and Stillwater Rivers resulting in maximum concentrations recorded on April 26th prior to initiation of the Quabbin transfer on May 16th of that year.

Table 12 - Wachusett Reservoir Nutrient Concentrations:
Comparison of Ranges from 1998-01 Database[1] to Results from 2002 Quarterly Sampling [2]

Sampling Station [3]	Ammonia (NH3; ug/L)		Nitrate (NO3; ug/L)		Silica (SIO2; mg/L)		Total Phosphorus (ug/L)		UV254 (Absorbance/cm)	
	1998-01	Quarterly'02	1998-01	Quarterly'02	1998-01	Quarterly'02	1998-01	Quarterly'02	2000-01	Quarterly'02
Basin North/3417 (E)	<5 - 12	<5 - 11	<5 - 124	<5 - 47	0.82 - 3.02	0.59 - 1.59	<5 - 13	<5 - 8	0.038 - 0.068	0.032 - 0.048
Basin North/3417 (M)	<5 - 36	<5 - 14	<5 - 138	28 - 55	1.41 - 3.31	0.77 - 1.73	<5 - 17	6 - 10	0.039 - 0.079	0.032 - 0.062
Basin North/3417 (H)	<5 - 34	6 - 41	49 - 190	48 - 97	1.84 - 3.92	1.27 - 2.48	<5 - 14	6 - 8	0.038 - 0.069	0.032 - 0.043
Basin South/3412 (E)	<5 - 14	<5 - 11	<5 - 172	<5 - 53	0.88 - 3.84	0.56 - 1.66	<5 - 16	<5 - 17	0.035 - 0.085	0.031 - 0.049
Basin South/3412 (M)	<5 - 26	6 - 13	11 - 184	24 - 58	1.40 - 4.03	0.95 - 1.68	<5 - 22	<5 - 7	0.036 - 0.089	0.032 - 0.055
Basin South/3412 (H)	<5 - 36	7 - 44	49 - 224	56 - 87	1.89 - 4.13	1.64 - 2.42	<5 - 37	7 - 9	0.036 - 0.091	0.038 - 0.047
Thomas Basin (E)	<5 - 18	<5 - 11	<5 - 201	<5 - 130	1.13 - 5.00	0.62 - 4.23	<5 - 23	5 - 15	0.026 - 0.136	0.028 - 0.140
Thomas Basin (M)	<5 - 18	<5 - 14	<5 - 205	9 - 141	1.29 - 4.94	0.88 - 4.13	<5 - 22	6 - 15	0.026 - 0.147	0.031 - 0.146
Thomas Basin (H)	<5 - 21	<5 - 14	<5 - 236	10 - 134	1.26 - 4.99	0.92 - 4.18	<5 - 22	5 - 15	0.027 - 0.150	0.028 - 0.131

Notes: (1) 1998-01 database composed of 1998-99 year of monthly sampling and subsequent quarterly sampling through December 2001, except for measurement of UV254 initiated in 2000 quarterly sampling
(2) 2002 quarterly sampling conducted May, July, October, and December
(3) Water column locations are as follow: E = epilimnion/surface, M = metalimnion/middle, H = hypolimnion/bottom

The low silica concentrations measured in 2002 occurred mainly in July, especially in samples collected in the epilimnion and metalimnion. At this time of year, consistent with a seasonal pattern that recurs annually, uptake of silica by diatoms and their subsequent sedimentation causes the store of this nutrient to be depleted in upper portions of the water column. In 2002, this seasonal demand for silica was superimposed on concentrations already relatively low due to the robust transfer from Quabbin. The combination of these factors contributed to the minimum silica concentrations observed in 2002.

The low UV absorbance values measured in 2002 occurred mostly in October when the cumulative volume of water transferred from Quabbin amounted to a record high 208 million cubic meters or 83 percent of the Wachusett basin volume. This degree of dilution with Quabbin water with its much lower UV absorbance value (averaging 0.02 A/cm at the point of entry into the Quabbin Aqueduct), contributed to the minimum UV absorbance values observed in 2002 in Wachusett Reservoir.

Another indication of the divergent influences of the Quabbin transfer and the Wachusett watershed on reservoir water quality is evident in samples from Thomas Basin. At this location in 2002, the concentrations and intensities of most parameters are elevated in May and again in December (see Appendix). The transfer from Quabbin was weakest at these times during 2002 resulting in the influence of the Quinapoxet and Stillwater Rivers becoming strongly evident in Thomas Basin which is the sampling location closest to the point of discharge of these rivers.

In summary, the relatively low concentrations observed in 2002 reflect the early entry and greater proportion of Quabbin derived water occupying the basin. Other than values at the low end of the ranges of nutrient concentrations discussed above, the seasonal and vertical patterns in the distribution of nutrients in 2002 quarterly samples were comparable to those documented in the historical database. These patterns include low epilimnetic concentrations in summer resulting from phytoplankton uptake and higher concentrations accumulating in the hypolimnion due to microbial decomposition of sedimenting organic matter. The annual cycle of nutrient dynamics in Wachusett Reservoir is detailed in the Water Quality Report: 1999 - Wachusett Reservoir and Watershed (MDC/DWM, 1999). Future nutrient sampling at Wachusett Reservoir is planned to continue on the quarterly schedule.

4.4 ALGAE

Algae samples were collected once per week during the year from the back of the Cosgrove Intake. Grab samples were taken from the surface and at six, eight, ten, twelve, and fourteen meters using a 2 liter Van Dorn bottle. Samples were not collected four times during the year (once each in January, March, November, and December) due to scheduling conflicts or equipment problems.

A total of 282 discrete samples were collected and analyzed. Half liter samples were concentrated to twelve mL by gravity filtration through sand and silk in Sedgwick-Rafter (SR) funnels. A one mL subsample was placed in a SR counting cell, allowed to settle for fifteen minutes, and then examined at 100X magnification. Algae were identified and counted in three strips comprising approximately ten percent of the subsample. The underside of the coverslip was also scanned to observe any floating bluegreen algae (*Anabaena*) or mobile golden-browns (*Synura*, *Uroglena*, *Dinobryon*).

Only golden-brown genera were identified and counted in samples collected from 6m, 10m, and 12m depths. Detection of mobile golden-brown genera was enhanced by using a 7 - 45X stereozoom dissecting microscope to scan the entire cell prior to a detailed examination at 100X.

Data collected are located in an appendix to this report. They are also accessible as part of an electronic database (Microsoft EXCEL file Algae02.xls) and on paper at the MDC-DWM Water Quality Lab in West Boylston, Massachusetts.

Taxonomic composition, density, and seasonal dynamics of the plankton community throughout Wachusett Reservoir were evaluated through an additional program of quarterly sampling at three sampling stations within the basin. Transparent vinyl tubing (1 inch O.D. x 3/4 inch I.D.) was used to collect depth-integrated samples. The weighted end of the tube was lowered from the surface to a pre-selected depth, the surface end of the tube stoppered to prevent loss of water during tube retrieval, and the tube retrieved with an extracted "core" of the water column. The water in the tube was transferred into a polyethylene bottle (4 liter capacity measuring approximately 30 cm high and 15 cm in diameter) rendering a composite sample of plankton over that depth.

Integrated samples were generally collected to a depth of fifteen meters, which was approximately the depth to the bottom of the metalimnion (and "interflow" stratum; see Section 4.2.2 above) during the period of thermal stratification. Data from water column profiles of dissolved oxygen and hydrogen ion activity (pH) indicate that most photosynthetic activity occurs in the epilimnion and metalimnion which were represented in their entirety in the samples integrated to fifteen meters. This sampling depth was maintained during non-stratified conditions to provide consistency in the data.

Samples were preserved in the field with Lugol's Solution (3 ml per 1,000 ml of sample according to <u>Standard Methods</u>) and transported to the lab for processing. Prior to microscopic analysis, all samples were concentrated by a process of sedimentation. This entailed keeping the sample bottles undisturbed for a least one week to allow the organisms to settle to the bottom and then decanting the overlying supernatant in each bottle with a peristaltic pump. The one week minimum sedimentation period surpasses the EPA (1973) guideline of 4 hours per 1 cm depth of sample bottle. Samples were concentrated generally between 5% and 15% of their original volume by this process. Final results reported for each sample will incorporate the appropriate correction factor.

In addition to the quantitative samples of plankton collected with the integrated tube sampler, a net was used to collect qualitative samples of the larger forms of plankton. A plankton net of 35 micron mesh was manipulated vertically in the water column at Station 3417 (Basin North) in conjunction with monthly collection of integrated tube samples. The net filters and concentrates plankton from an unknown quantity of water and cannot provide estimates of density, but does enable the relative abundances of the larger forms to be determined.

Microscopic analysis of plankton samples was performed with a compound microscope capable of magnification from 40 to 1,000 times and using phase-contrast illumination. Plankton taxa in the integrated samples were enumerated using a Sedgewick-Rafter (S-R) Cell which enables plankton densities to be quantified. Each concentrated sample was inverted a few times to homogenize the sample and then 1 ml of the sample was withdrawn with a pipette and placed into the S-R Cell. Approximately 15 minutes were allowed for the plankton to settle to the bottom of the S-R Cell before enumeration. Plankton were enumerated in a total of 10 fields described by an ocular micrometer. At 200X magnification, the ocular field measures 0.3136 square millimeters in area (previously calibrated with a stage micrometer) and the fields were selected for viewing at approximately 0.5 cm intervals across the length of the S-R Cell.

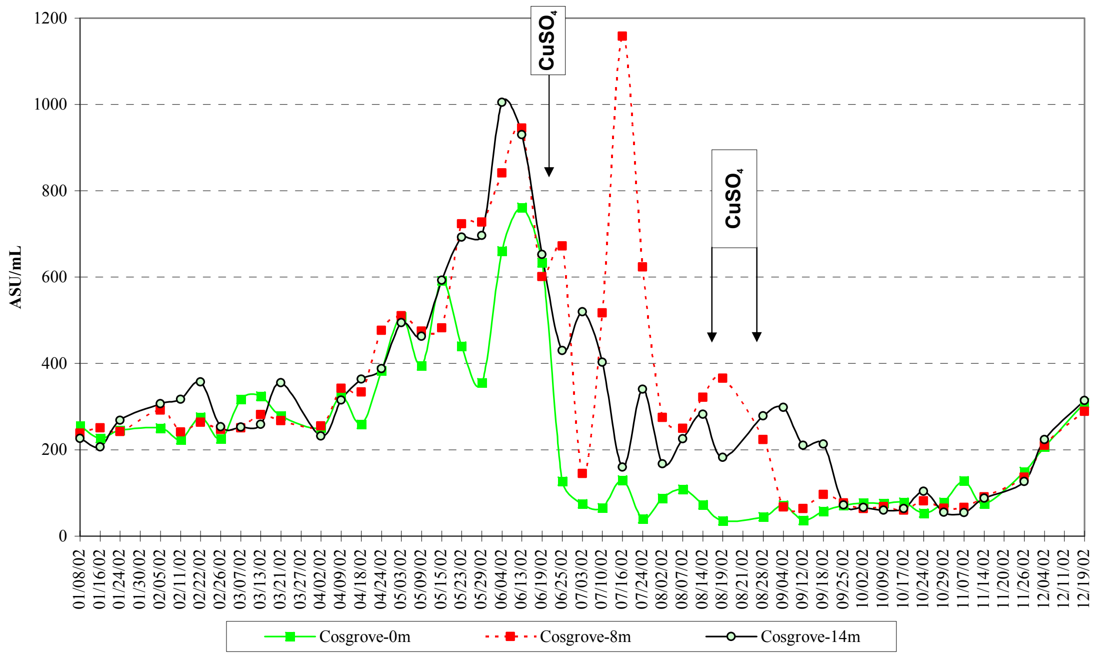
Plankton densities were expressed as Areal Standard Units (ASUs; equivalent to 400 square microns). The area of each specimen viewed in each counting field was estimated using the ocular micrometer (the ocular field was divided into a 10 by 10 grid, each square in the grid having an area of 3,136 square microns or 7.84 ASUs at 200X magnification). In the case of taxa which form gelatinous envelopes or sheaths, such as *Microcystis*, the area of the envelope was included in the estimate for that specimen. The areal extent of certain colonial taxa, such as the diatoms *Asterionella* and *Tabellaria*, was estimated by measuring the dimensions of one cell and multiplying by the number of cells in the colony. Cell fragments or structures lacking protoplasm, including lorica of *Dinobryon*, diatom frustules, and thecae of dinoflagellates were not counted.

Phytoplankton and zooplankton were generally identified to genus, although copepods were identified only to suborder (Calanoida or Cyclopoida). An effort was made to identify dominant forms of plankton to species. Analysis of preserved plankton samples collected quarterly is still in progress and will be reported in a later publication.

Algal populations at the Cosgrove Intake during 2002 were unremarkable and followed one of the two standard patterns. Total algae concentrations were low and relatively stable through early April. Concentrations increased at all depths in April, May, and early June, reaching a maximum of 1000 ASU/mL at fourteen meters and 760 ASU/mL at the surface. The reservoir was treated with copper sulfate in mid June to control *Anabaena* and total algae concentrations at the surface and at eight meters sharply declined. A steady decline was also noted at fourteen meters. Total algae concentrations at eight meters rebounded in July and then declined without treatment. Surface concentrations remained low, but concentrations at eight and fourteen meters began to increase again in August, when the MWRA treated the reservoir two more times to control *Synura*. Total algae concentrations declined to less than 100 ASU/mL and remained low until November, when normal increases in diatoms elevated total algae concentrations to just over 300 ASU/mL (Figure 9).

FIGURE 9

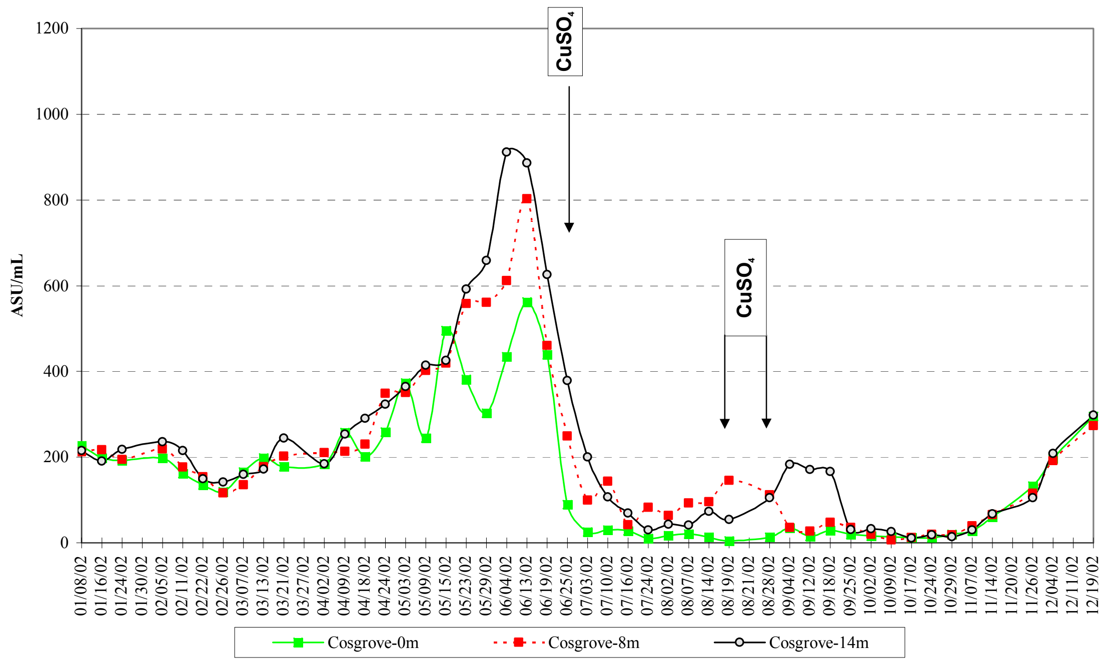
COSGROVE INTAKE
Total Algae



The reservoir algal community was comprised primarily (50-91%) of diatoms from January through June. *Asterionella* was often the dominant genus (up to 70% of total algae), but centric diatoms (40% of the total in June) and *Rhizosolenia* (31% in May) were also important components of the algal community. Diatoms again reached greater concentrations and remained dominant for a longer period at depth than at the surface. Populations at all depths reached an annual maximum in June (more than 900 ASU/mL at fourteen meters and nearly 600 ASU/mL at the surface) and then declined sharply following a copper sulfate treatment. It should be noted that total diatom concentrations were actually declining prior to the initial copper sulfate treatment (Figure 10). Diatom concentrations remained below 200 ASU/mL at all depths through the summer and were not impacted by the second or third copper sulfate treatment. An increase in diatoms was observed at depth at the end of the summer (see Figure 10), but concentrations declined again without treatment. Total diatom concentrations remained low but began to slowly increase in November and December. More than 85% of the algal community was made up of diatoms by late November; over 95% were diatoms by the end of the year. The predominant genus (78% of the total) was again *Asterionella*.

FIGURE 10

COSGROVE INTAKE
Total Diatoms



Bluegreen algae were present at very low concentrations until the beginning of June, with total numbers never exceeding 10 ASU/mL. Numbers rose at the surface in mid June as *Anabaena* began to increase, but the northern end of the reservoir was immediately treated with copper sulfate. This quick response suppressed the annual bloom of *Anabaena* once again, with *Anabaena* concentrations never exceeding 45 ASU/mL. Only very low concentrations of this problematic genus have been noted during the past three years due to prompt treatment, eliminating the annual taste and odor problems of the past. Bluegreen concentrations rose sharply in July and August due to a bloom comprised primarily of the colonial alga *Microcystis* (Figure 11). Concentrations at eight and fourteen meters were as high as 100 ASU/mL, while samples from the surface never exceeded 50 ASU/mL. These concentrations were lower than what has been common over the past few years, but *Microcystis* continues to make up a significant proportion of the summer bluegreen population. A second and third treatment with copper sulfate was done in August to reduce concentrations of *Synura* and to avoid the development of taste and odor problems. Bluegreen algae concentrations at all depths were significantly reduced and remained at low levels for the remainder of the year (Figure 11).

Green algae were present at all depths throughout the year, with maximum concentrations between fifty and seventy ASU/mL during the spring and summer. Concentrations were below 20 ASU/mL until the end of April and from November to the end of the year (Figure 12). Green algae comprised 7% – 25% of the total algal population through the summer and as much as 53% in the fall when diatoms and bluegreens were both in decline, with a smaller percentage generally present during the remainder of the year.

FIGURE 11

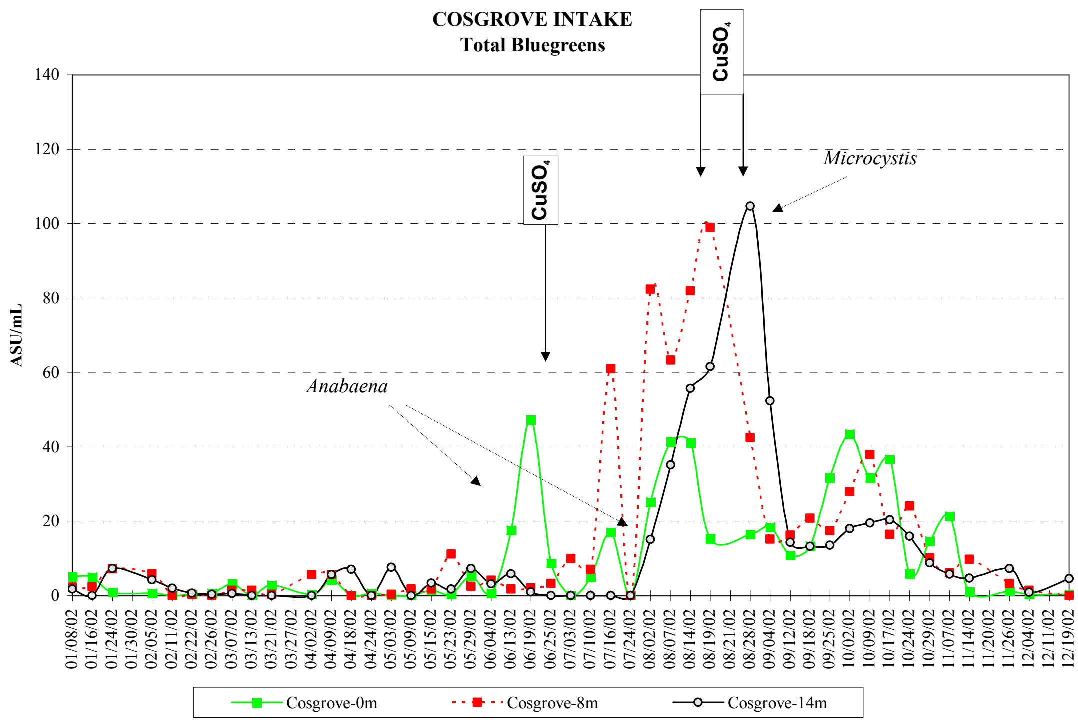
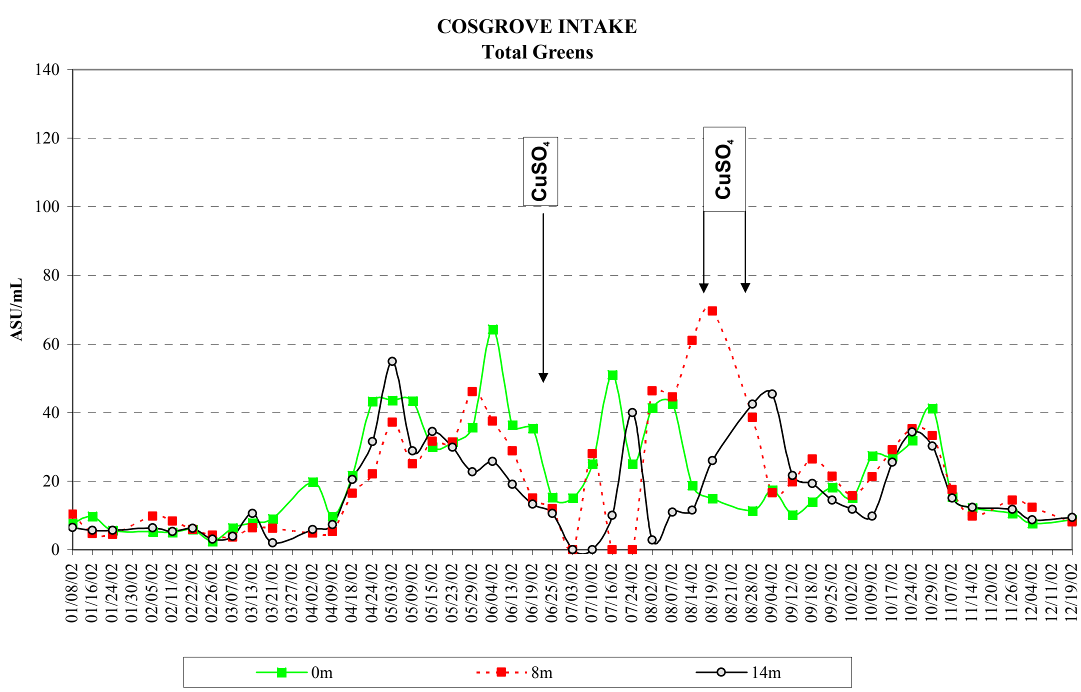
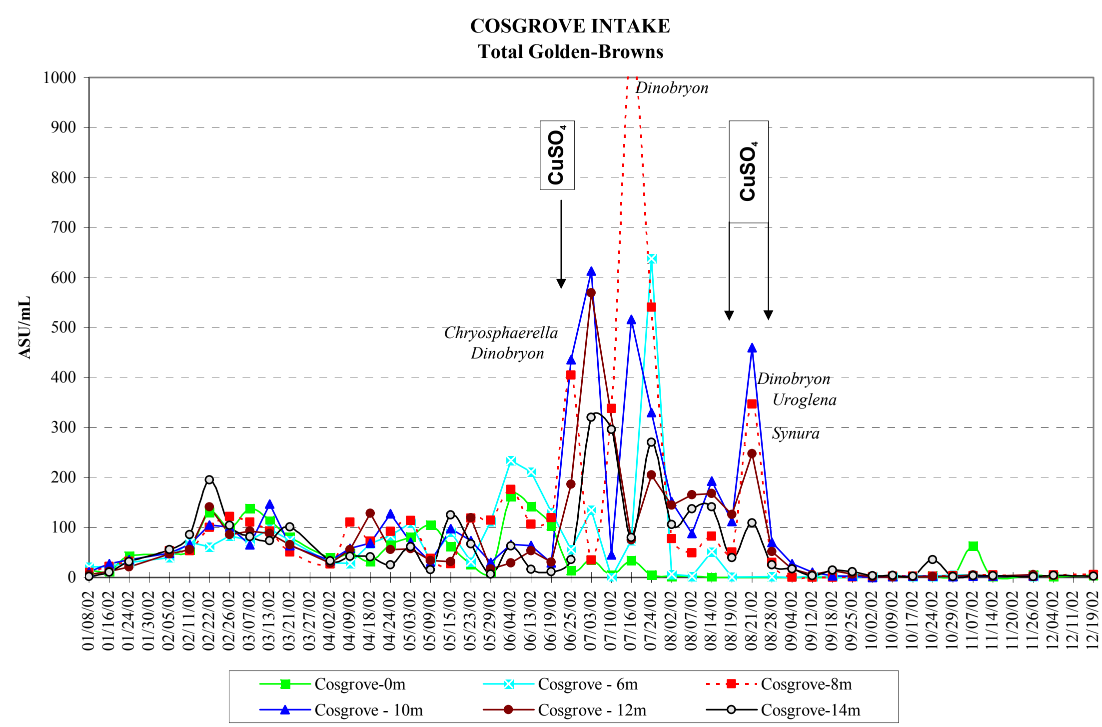


FIGURE 12



Golden-brown algae were present in low concentrations at all depths until mid June. The MWRA treated the reservoir with copper sulfate to control a bloom of *Anabaena* on June 20th and both *Chrysosphaerella* and *Dinobryon* had increased significantly by the following week, especially at a depth of ten and twelve meters. Total golden-brown algae concentrations increased from 250 ASU/mL to 600 ASU/mL (Figure 13). *Dinobryon* concentrations at eight meters were greater than 900 ASU/mL during July. Golden-brown algae concentrations declined at all depths in early August to less than 200 ASU/mL, but the MWRA treated the reservoir with copper sulfate on August 15th to control *Synura* and once again golden-browns increased following the application. *Dinobryon* and *Uroglena* were the dominant genera, although *Synura* remained present in excess of the 20 ASU/mL treatment threshold. The MWRA added copper sulfate to the reservoir again on August 22nd and concentrations of all golden-brown genera dropped sharply. Total concentrations remained low (<10 ASU/mL) at all depths for the remainder of the year except for two samples in October and November when *Uroglena* colonies were observed and total golden-brown concentrations were between 30 and 70 ASU/mL.

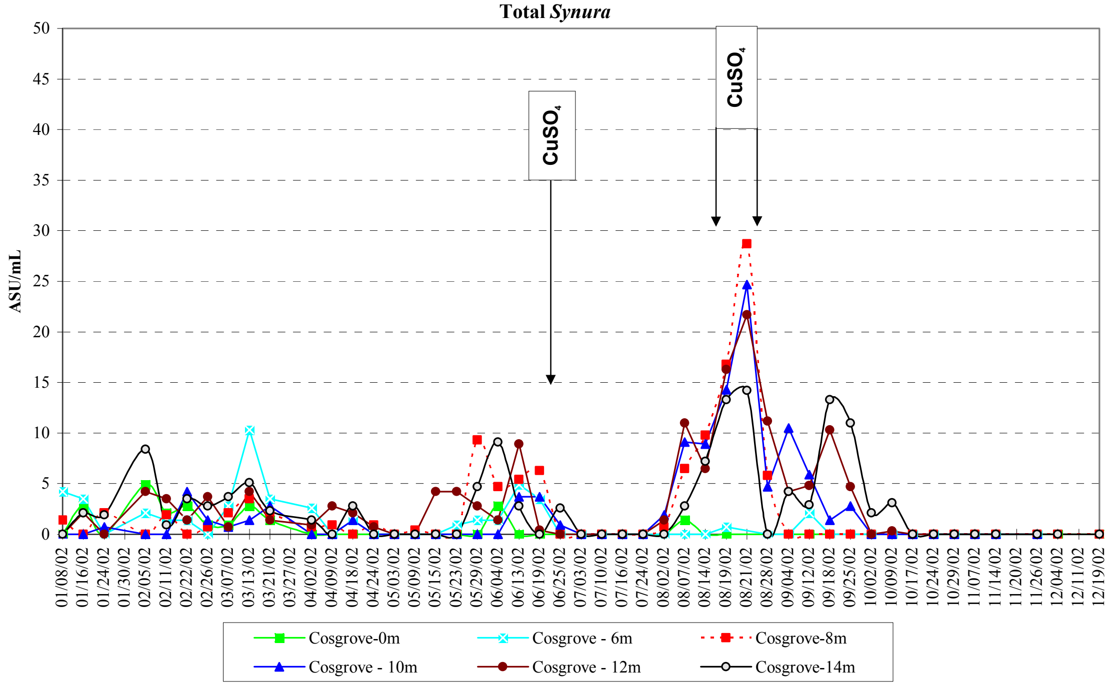
FIGURE 13



Synura concentrations were low during much of the year, but the problematic golden-brown was present in most samples from January through May (Figure 14). *Synura* was more prevalent in the water column at the end of May and during June, but was eliminated by the initial copper sulfate treatment in June. Concentrations rose during August (especially at eight, ten, twelve, and fourteen meters) and were between fifteen and thirty ASU/mL. The MWRA added copper sulfate twice in seven days, and *Synura* was not detected at any depth for the rest of the year.

FIGURE 14

COSGROVE INTAKE
Total *Synura*



4.5 MACROPHYTES

The macrophyte flora of Wachusett Reservoir is composed of approximately twenty species including three species alien or non-native to Massachusetts (Table 13). The alien species posing the greatest potential threat to water quality is Eurasian Water-milfoil (*Myriophyllum spicatum*) and this plant is the focus of intensive control efforts initiated in 2002 (see adjoining section on Eurasian Water-milfoil). The paragraphs that follow provide details on the composition and distribution of the Wachusett Reservoir macrophyte community.

4.5.1 LITTORAL ZONE CHARACTERISTICS AND MACROPHYTE DISTRIBUTION

Wachusett Reservoir has a shoreline totaling about 59 km (36.7 miles) in length. The outline of the basin is elongated and convoluted with many bays and coves due to the reservoir's origin as a flooded river valley. The complexity of a basin's shoreline can be quantified using the morphometric parameter known as "shoreline development". Shoreline development is the ratio of the length of the shoreline to the circumference of a circle equal in area to that of the basin. Many lake basins are subcircular or elliptical in shape with shoreline development values around 2.0, but Wachusett Reservoir has a value of 4.2 due to its intricate outline.

Characteristics of the littoral zone associated with this extensive shoreline vary greatly according to location. Major types of littoral zone substrates include wave-washed cobble facing prevailing winds, bedrock outcrops, sandy substrates derived from bluffs of glacial outwash, and rip-rap boulders armoring dikes. Most importantly, deposits of fine organic sediment exist in the four basins composing the upper reaches of the system and in coves of the main basin as a result of these locations receiving loads of suspended solids from tributary streams and being protected from high energy wind and wave action. Nearly all macrophytes growing in Wachusett Reservoir are located in these latter sub-basins and coves due to their need for fine-grained organic substrates to take root and extract nutrients.

Stillwater Basin comprises the uppermost reach of the reservoir system. Due to its position at the downstream terminus of the Stillwater River drainage system, fine organic sediments have been deposited over extensive areas in relatively shallow water creating ideal habitat for macrophytes. Discharge from the Stillwater River also delivers macrophyte propagules (seeds or vegetative fragments) from various sources in the watershed. As a result of these factors, Stillwater Basin supports the greatest diversity of macrophytes found anywhere in the reservoir system (Table 13). In contrast, coves lacking significant tributary inflows and associated deposits of fine organic sediment such as Flagg Cove (South Bay), Lord Cove, and Prescott Cove support only minimal macrophyte growth.

Macrophytes inhabiting Wachusett Reservoir, including alien and native species, are generally submergent in growth from. Exclusively floating-leaved species such as water lilies are absent and emergent species such as sedges and rushes are restricted to the vicinity of stream inlets due to fluctuating water levels in the reservoir.

4.5.2 ALIEN MACROPHYTE SPECIES

The alien or non-native species of macrophyte present in Wachusett Reservoir consist of the following: Eurasian Water-milfoil (*Myriophyllum spicatum*), Variable Water-milfoil (*Myriophyllum heterophyllum*) and Fanwort (*Cabomba caroliniana*). Eurasian Water-milfoil was first documented in the northern portion of Stillwater Basin in 1999 and has expanded its distribution since that time (Table 13). This invasive plant is the focus of intensive control efforts initiated in 2002 and is discussed in Section 4.6.

Variable Water-milfoil and Fanwort are indigenous to North America, but originally ranged west and/or south of New England so are considered alien in Massachusetts. Variable Water-milfoil is less aggressive than the Eurasian species and its impacts to water quality are generally less severe. As a vigorous competitor of the Eurasian species, stands of Variable Water-milfoil function beneficially to delay and restrict the spread of Eurasian Water-milfoil in the reservoir ecosystem.

Table 13 - Macrophyte Distribution in the Wachusett Reservoir Ecosystem

Scientific Name[1]	Common Name	Sub-basins Composing the Upper Reaches				Coves of the Main Basin							
		Stillwater Basin	Quinapoxet Basin	Upper Thomas Basin	Thomas Basin	Beaman Pond Cove	Gates Cove	Malagasco Cove (S. Bay)	Muddy Cove (S. Bay)	Lamson Cove	Andrews Harbor	Kendall Cove	Hastings Cove
Acorus americanus	Sweet-flag					X						X	
Cabomba caroliniana	Fanwort (alien)	X		X									
Ceratophyllum demersum	Coontail	X		X									
Elodea nuttalli	Waterweed	X	X	X	X	X		X				X	X
Eriocaulon aquaticum	Pipewort		X					X				X	
Isoetes sp.	Quillwort											X	X
Myriophyllum heterophyllum	Variable Water-milfoil (alien)	X	X	X	X	X	X	X	X				X
Myriophyllum spicatum	Eurasian Water-milfoil (alien)	X		X	X	X							
Najas flexilis	Naiad	X		X									
Nitella sp. (macroalga)	Nitella	X		X	X							X	
Potamogeton epihydrus	Leafy Pondweed	X						X					
Potamogeton perfoliatus[2]	Clasping-leaved Pondweed	X		X	X	X	X	X	X	X	X		X
Potamogeton pulcher	Spotted Pondweed					X							
Sagittaria graminea	Arrowhead		X	X	X	X		X					
Sparganium sp.	Bur-reed	X											
Utricularia purpurea	Purple Bladderwort	X							X				
Utricularia radiata	Bladderwort	X		X									
Veronica americana	American Brooklime	X											

NOTES:

(1) Species identifications based on Crow, G. E. and C. B. Hellquist. 2000Aquatic and Wetland Plants of Northeastern North America, Volumes 1 and 2The University of Wisconsin Press.

(2) This species also occurs outside sub-basins and coves; see report text

The presence of Variable Water-milfoil in Wachusett Reservoir was first documented by Richard McVoy of DEP in the mid-1990s. Field notes from a survey he conducted with Edward Brank of MDC on August 16, 1996 record that Variable Water-milfoil was mostly confined to Stillwater Basin and Thomas Basin, but also occurred as isolated stands in Beaman Pond Cove and Malagasco Cove of the main basin. These coves are associated with the inlets of Beaman Pond Brook (an intermittent stream adjacent to Gate 28) and Malagasco Brook in South Bay respectively. Mr. McVoy also noted the presence of Variable Water-milfoil in Quinapoxet Basin a year or two previous to the 1996 survey (personal communication). Observations recorded during routine macrophyte surveys initiated by MDC staff in 1999 indicate that this plant has expanded its distribution in the reservoir since 1996 to include Gates Cove, Muddy Cove (South Bay), and Hastings Cove in addition to the locations listed above (Table 13).

Fanwort is restricted to a patchy distribution in Stillwater and Upper Thomas Basins (Table 13). It was first documented in the reservoir system in 1999 as isolated specimens in Stillwater Basin. When encountered by divers during 2002 hand-harvesting efforts focused on Eurasian Water-milfoil, specimens of Fanwort were removed from Upper Thomas Basin.

The McVoy survey of 1996 is significant for documenting the absence as well as the presence of alien species. At that time, neither Eurasian Water-milfoil or Fanwort were observed in Stillwater Basin whereas Variable Water-milfoil and other species were noted at numerous locations throughout this basin. Observations recorded during routine macrophyte surveys initiated by MDC staff in 1999 establish that the earliest "pioneering" specimens of Eurasian Water-milfoil and Fanwort probably colonized Stillwater Basin in 1997 or 1998. The Stillwater River drains an area totaling 8,288 hectares (32 square miles) and it is likely that propagules of these alien species were delivered to Stillwater Basin in river flow from sources in this extensive watershed.

4.5.3 NATIVE MACROPHYTE SPECIES

The native Clasping-leaved Pondweed (*Potamogeton perfoliatus*) is the most widely distributed macrophyte in the reservoir system (Table 13). It occurs in most of the basins composing the upper reaches of the system and in coves of the main basin. It is unique among all rooted Wachusett macrophytes in having established itself outside of protected coves in areas exposed to greater wind energy, turbulent wave action, and having sandy sediments. Extensive beds of this plant are located along the base of Scar Hill Bluffs rooted at depths of between 10 and 14 feet, between Sholan Point and Davenport Point at the mouth of Lamson Cove, and in an area extending out from Greenhalge Point to the northeast toward Cemetery Island.

The next most abundant native macrophyte is Waterweed (*Elodea nuttalli*). This plant is generally low-growing and forms a dense understory layer beneath the taller pondweeds and milfoils, often in combination with Arrowhead (*Sagittaria graminea*). Both these species may be more widespread in coves of the main basin than indicated in Table 13 since specimens rooted in deep water may have been overlooked by observers in a boat and because of their habit of growing close to the substrate. Another low-growing species, Spike-rush (*Eleocharis acicularis*), has been observed floating on the surface in the main basin, apparently uprooted by turbulence or grazing waterfowl. The location of submerged beds of this latter species has not been determined, so it is not included in Table 13. More intensive sampling at depth with a grab or dredge is planned for the future to confirm the distribution of the three species discussed above.

The macroalga *Nitella* is another plant that grows close to the substrate. As an alga, this plant lacks roots and other structures typical of vascular plants, but has been observed forming a sparse network of growth over sediments at a variety of depths. It has occasionally been collected on anchors recovered from deep water in the main basin and likely is widespread throughout the reservoir system at depths beyond the limit of vascular macrophyte distribution.

4.6 EURASIAN WATER-MILFOIL IN WACHUSETT RESERVOIR

4.6.1 THE THREAT OF EURASIAN WATER-MILFOIL

The Wachusett Reservoir system is a major component of the drinking water supply for greater Boston. In August of 2001, a pioneering colony of Eurasian Water-milfoil (*Myriophyllum spicatum;* referred to subsequently as "milfoil") was observed for the first time in Upper Thomas Basin, a small basin in the upper reaches of the reservoir system. Milfoil is an exotic, invasive species of macrophyte known to aggressively displace native vegetation and grow to nuisance densities with associated impairments to water quality. Prior to 2001, this plant was restricted to the uppermost component of the reservoir system, Stillwater Basin, where its distribution has been monitored since 1999.

The expansion of milfoil into Upper Thomas Basin represents a significant increase in the risk of a potentially rapid and overwhelming dispersal of this plant into the main reservoir basin. The water quality implications of such an event are serious and include increases in water color, turbidity, phytoplankton growth, and trihalomethane (THM) precursors. These increases result from the function of this plant and macrophytes in general as nutrient "pumps", extracting nutrients from sediment and releasing them to the water column, mostly as dissolved and particulate organic matter.

This function is especially intense with milfoil due to its characteristically rapid and prolific growth habit. Nutrient release occurs during most life cycle stages, but especially during senescence and death. Milfoil also releases nutrients and organic matter during canopy formation (lower leaves and branches are sloughed as upper stems grow horizontally along the surface) and when undergoing a propagation process known as autofragmentation. Autofragments are stem segments with adventitious roots at the nodes that float upon abscission and are the plant's most important mode of reproduction and dispersal. Autofragments of milfoil eventually sink to the bottom and are capable of colonizing littoral zone areas having only minimal deposits of organic sediment.

The 2001 expansion of milfoil into Upper Thomas Basin prompted MDC to design a milfoil control program in preparation for the 2002 growing season. Implementation of the control program was accomplished through funding provided by the MWRA with technical assistance from the MDC. Working together, these agencies selected the consulting firm Aquatic Control Technology, Inc. (ACT) of Sutton, Massachusetts to conduct a variety of control techniques aimed at eliminating the infestation in Upper Thomas Basin, preventing the establishment of new plants, and restricting the dispersal of autofragments downgradient to other portions of the reservoir system. A description of the 2002 milfoil control program conducted by ACT is provided in the sections that follow.

4.6.2 MILFOIL CONTROL PROGRAM: OBJECTIVES, METHODS, AND 2002 ACTIVITIES

The original intent of the milfoil control program was to keep Upper Thomas Basin free of milfoil so as to function as a "fire break" against dispersal of this plant into the main reservoir basin. The program was designed to eliminate the pioneering colony in Upper Thomas Basin and prevent or remove any future incursions of milfoil originating from the population established in Stillwater Basin through the use of benthic barriers and hand-harvesting. Benthic barriers are sheets of material installed over bottom substrates to smother existing plant infestations and/or prevent colonization of the substrate. Hand-harvesting consists of SCUBA divers physically uprooting specimens of milfoil and removing the plants by hand. Hand-harvesting is intended to preserve populations of native macrophytes as these provide the first line of defense against the establishment of new specimens of milfoil.

Another objective of the program was to restrict the movement of autofragments into downgradient portions of the reservoir system through deployment of floating fragment barriers at strategic locations. These locations consisted of the railroad bridge "bottleneck" between Stillwater Basin and Upper Thomas Basin, the northern end of Upper Thomas Basin confining the area of worst infestation observed in 2001, and the Beaman Street Bridge "bottleneck" between Upper Thomas Basin and Thomas Basin proper.

Despite implementation of these techniques and the removal of large quantities of milfoil, dispersal and regrowth by this invasive plant has enabled the infestation to spread throughout Upper Thomas Basin. The original 2001 infestation of milfoil in Upper Thomas Basin was mostly limited to a 2 acre (0.8 hectare) area of growth located at the extreme northern end adjacent to the railroad bridge "bottleneck" where water enters from Stillwater Basin located upgradient. This was the area targeted for benthic barriers in the original design of the milfoil control program. Over the course of the 2002 growing season, milfoil appeared along most of the eastern shoreline and on a small central "plateau" of relatively shallow water in Upper Thomas Basin. Much of this milfoil had been removed by hand-harvesting by early August, but aggressive regrowth became evident a few weeks later. Additional scouting in 2002 revealed the presence of pioneering specimens of milfoil in Thomas Basin proper and even in the main body of Wachusett Reservoir (see below under Hand-Harvesting). It is likely that these specimens originated as fragments from the population that became established at the northern end of Upper Thomas Basin in 2001.

Summaries of each of the main components of the 2002 milfoil control program are given in the sections below. All of the tasks were conducted by staff from ACT with oversight and assistance provided by MDC.

Surveys Using Global Positioning System (GPS)

An initial "pre-treatment" survey of Upper Thomas Basin was conducted on May 1st. Observations of macrophyte distribution and density, substrate composition, and water depths were recorded at multiple points along transects across the basin. These data were recorded in conjunction with GPS measurements to enable accurate mapping of the information. Hand-harvesting in Upper Thomas Basin had concluded in August when divers reported no more specimens to target for removal and a visual inspection confirmed nearly complete control of milfoil (see below under Hand-Harvesting). However, a "post-treatment" survey of Upper Thomas Basin on September 11th revealed significant regrowth of milfoil and triggered renewed efforts at hand-harvesting. GPS surveys were also conducted in Stillwater Basin (October 2nd) and Thomas Basin proper (October 8th and 15th) after it was determined that baseline data for these basins would be important for future milfoil control efforts and were added as supplementary tasks to the scope of the original program. Results of these surveys are detailed in a comprehensive report prepared by ACT at the conclusion of the program (ACT, 2002).

Floating Fragment Barriers

The initial deployment of floating fragment barriers was completed on June 6th with 250 feet placed across the northern end of Upper Thomas Basin to confine the two acre area of worst infestation and another fifty feet placed across the gap under the RR Bridge "bottleneck" between Stillwater Basin and Upper Thomas Basin. On July 8th, a fifty foot section from the containment area in Upper Thomas was removed to be repositioned across the gap under the Beaman Street Bridge "bottleneck" between Upper Thomas and Thomas Basin proper. Barrier material loaned from ACT was used to replace this repositioned section and maintain the integrity of the containment area until delivery of an additional 100 foot section of barrier purchased as part of the project. The new section was added to the existing barrier on September 26th. The total 300 foot length delimiting the southern boundary of benthic barrier coverage in Upper Thomas Basin functioned to reduce the rate of sediment deposition on the benthic barriers and thereby decrease the need for future maintenance. The floating fragment barriers were retrieved and placed in storage before the onset of ice formation.

Benthic Barriers

Installation of benthic barriers was initiated on June 18th and completed on July 3rd. A total of 72 panels of barrier material, each measuring 1,200 square feet (24' x 50'), were installed to cover the two acre area of worst infestation at the northern end of Upper Thomas Basin. Lengths of steel "re-bar" were laid down over each panel to anchor the barrier material. Subsequent maintenance of the benthic barriers has entailed creating small punctures or slits in barrier material that has billowed up from the bottom due to build-up of entrapped gases. Most billowing has occurred at the extreme northern end of Upper Thomas Basin in shallow water where benthic barriers cover deposits of organic-rich sediment.

Hand-Harvesting

Hand-harvesting of milfoil was initiated on July 8th. Initial efforts were directed at removing scattered patches of milfoil and individual specimens located along the eastern shoreline and on a central "plateau" of relatively shallow water in Upper Thomas Basin. Two divers conducted this work through July 22nd. From July 23rd through July 26th, additional divers were added to the crew for a total of four or five divers performing hand-harvesting in Upper Thomas Basin and also in Thomas Basin proper where scattered specimens had been observed along the shoreline immediately south of the Beaman Street Bridge and along the bridge causeway to the west. A final period of hand-harvesting by two or three divers was conducted from July 29th through August 5th. By this time, a total of 356 diver-hours had been logged resulting in the removal of an estimated 60 to 72 thousand individual milfoil plants. Control of the milfoil appeared nearly complete with no specimens evident for targeting by divers. This was confirmed by a visual inspection of Upper Thomas Basin on August 23rd when only two specimens of milfoil were observed and native macrophyte species appeared to be flourishing in response to milfoil removal.

A "post-treatment" survey of Upper Thomas Basin conducted on September 11th and significant regrowth of milfoil was observed. A second stage of hand-harvesting was conducted from October 1st through October 9th. As part of this effort, divers were initially directed to remove specimens of milfoil that had been observed in the small cove south of Gate 28 in the main body of Wachusett Reservoir (just east of the Route 140 Bridge under the power lines). Close inspection of this cove resulted in the removal of fourteen specimens of milfoil before divers returned to work in Upper Thomas Basin. Hand-harvesting there was finally terminated because the plants had become fragile and too easily fragmented. This second stage of hand-harvesting logged a total of 132.5 diver-hours with an estimated 18 to 22 thousand specimens removed. ACT reported that significant milfoil regrowth remained unharvested along the eastern shoreline and on the central "plateau" of Upper Thomas Basin.

4.6.3 PLANS FOR MILFOIL CONTROL EFFORTS IN 2003

It is evident from observations of milfoil dispersal and regrowth during the 2002 control program that this plant will require attention over the long-term if infestations throughout the main body of Wachusett Reservoir are to be prevented. Next year, the floating fragment barriers purchased through ACT in 2002 will be redeployed by MDC staff. Similarly, MDC staff will alleviate billowing in the benthic barriers and perform minor maintenance over the next few years until they require significant cleaning or repositioning. However, two techniques that are important for ongoing milfoil control efforts will require the procurement of contractor services. Details of these techniques are given below.

Continuation of Hand-Harvesting

Next year, during the 2003 growing season, MDC plans call for early initiation of intensive hand-harvesting. Early efforts will focus on harvesting the plants known to have regrown in Upper Thomas Basin and not removed last season. Dive crews will be available for hand-harvesting the entire summer in the likely event that regrowth occurs subsequent to initial harvesting efforts.

The effort planned for 2003 will approximately match the effort concluded this year which totaled 488.5 diver-hours. The figures from ACT accounting of hand-harvesting efforts in 2002 indicate that the cost of one diver-hour is about $90 including the pay rates for lead and secondary divers and support from a field technician working topside in a boat. This effort will also include spring and fall macrophyte surveys of Upper Thomas Basin aided by GPS for the purpose of updating existing macrophyte assemblage maps and evaluating hand-harvesting effectiveness.

Associated with hand-harvesting efforts, frequent scouting for milfoil throughout the reservoir system will be continued by MDC to identify and target any pioneering specimens found in new areas. Scouting and hand-harvesting will be sustained as long as milfoil is evident anywhere in the system downgradient of Stillwater Basin.

Biological Control of Milfoil in Stillwater Basin

Recent research by MDC staff into the feasibility of biological control of milfoil through introduction of a native insect that grazes on the plant, the milfoil weevil (*Euhrychiopsis lecontei*), indicates that it offers the potential for long-term control of the infestation throughout the reservoir system. MDC consultation with a milfoil weevil specialist substantiate that the extent, continuity, and density of the infestation in Stillwater Basin is suitable for successful weevil introduction and also that the adjacent uplands provide ideal over-wintering habitat for adult weevils. Based on its status as a native insect, introduction of the weevil requires no permits.

No conventional techniques are practicable for controlling milfoil in Stillwater Basin due to the extensive area of infestation and the likelihood of constant reintroductions into this basin via autofragment delivery in Stillwater River flow. Most of this basin supports macrophyte growth consisting of a mixture of milfoil and native plants totaling about 10 hectares (25 acres). The Stillwater River drains an area totaling 8,288 hectares (32 square miles) and the infestation in Stillwater River Basin likely originated around 1997-98 from sources in this extensive watershed (see previous section on macrophytes).

Plans call for a modest initial program entailing the introduction of ten thousand weevils, comprised primarily of eggs and larvae. These will be stocked at Stillwater Basin sites agreed upon by the contractor and MDC. The biological control program also includes an initial baseline survey (pre-introduction) and two post-introduction surveys conducted by the contractor. Biological control has the potential to augment the physical control methods now practiced in Upper Thomas Basin. Establishment of a weevil population in Stillwater Basin may lead to suppression of milfoil beyond the limits of the original stocking area and reduce the costs associated with future hand-harvesting efforts.

5.0 SUMMARY OF SITE INVESTIGATIONS

A total of seventy-eight sites were investigated during 2002. A majority of the problems at these locations were related to residential development (17), road reconstruction (8), wetland encroachment (7), septic systems (7), or spills of hazardous materials (7). Other problems addressed included right-of-way issues, forestry operations, horses, stormwater management, commercial development, encroachment on Division property, and sewer construction.

Problems at fifty-six of the seventy-eight sites were addressed and are now considered resolved. Fourteen sites are currently on watch status. Work at these sites is being monitored and additional activities are necessary in some cases, but the Division is confident that successful resolution of these issues will occur. Problems at these sites are associated with road repairs, sewer construction and connection, residential construction, and forestry operations.

Eight sites remain active. Three involve problems with failing septic systems in the Sterling Campground area. The Division continues to work with the Sterling Board of Health to try and find a reasonable solution. The owner of a failing septic system on Maple Street in West Boylston has been instructed to connect to the municipal sewer, but has not yet complied. The remaining four issues include a spill in the industrial area of Holden, construction of a parking lot in West Boylston, encroachment on Division property (a horse trail), and a residential driveway on Route 140 in Sterling. Efforts to resolve all problem sites continues even as additional inspections are carried out during 2003.

6.0 SAMPLING PLAN FOR 2003

The Wachusett watershed sampling program for 2003 will once again include special studies, enforcement actions, incident response, and routine sampling and analysis. The routine sampling program will attempt to separate out the effects of storm events on tributary and reservoir water quality from standard dry weather water quality data. The program was designed to protect public health, identify current and potential threats to water quality, and further our understanding of the reservoir and its tributaries.

Fecal coliform and conductivity will be measured weekly at eighteen stations on thirteen tributaries during dry weather. Quarterly nutrient samples will be collected from nine tributary stations with available flow data. The stations sampled include all significant tributaries that discharge directly to the reservoir. Separate wet weather sampling of all routinely sampled tributaries will be done to help quantify bacterial loading to the reservoir from storm events. Tributary sampling will take place immediately following rain events (first flush) and then all stations will be resampled after 24 and 48 hours to see how long elevated fecal coliform concentrations persist after a storm. Precipitation amounts, groundwater levels, and stream flows will all be carefully documented and compared to bacteria numbers to attempt to further refine our understanding of the causes of elevated fecal coliform levels in Wachusett tributaries.

Fecal coliform bacteria samples will be collected daily four days per week at the Cosgrove Intake and from the Route 12 Bridge at the upper end of the reservoir when ice conditions allow. Monthly temperature, dissolved oxygen, pH, and conductivity profiles will be taken at three reservoir stations (3417-Basin North, 3412-Basin South, and Thomas Basin) during ice-free periods using a Hydrolab H20 Sonde Unit and a Surveyor III data logger. More frequent profiles will be collected when necessary to document changing conditions in the reservoir. Algae samples will be collected weekly or biweekly at multiple depths from the Cosgrove Intake or mid reservoir station 3417, and quarterly from Thomas Basin and mid reservoir station 3412. Samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorus, and silica will be collected quarterly from 3417, 3412, and Thomas Basin.

The movement of water and contaminants through the reservoir, especially during times when water is being transferred to Wachusett Reservoir from Quabbin Reservoir, remains the focus of significant interest. Sampling of the reservoir surface will continue on a regular basis. Monthly, biweekly, or weekly transect sampling will be done when feasible to help further understand the effect of water movement on fecal coliform levels throughout the reservoir.

A study of the movement of pathogens during storm events was initiated by UMASS in 2002 with funding from the American Water Works Association Research Foundation and the cooperation of the MDC Division of Watershed Management. The study is designed to look at different land uses (agriculture, residential, forest) and determine how best to monitor pathogens and their movement through the watershed during both wet and dry conditions throughout the year. This information will be used to optimize future sampling programs and to more accurately predict potential public health problems. Division staff have supported this work by collecting samples, maintaining field equipment, and performing bacterial analyses. Continued work on the study is planned through 2003.

Sampling of the Pinecroft area drainage basin will continue in order to evaluate the impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling established baseline and stormwater nutrient and bacteria levels and profiled water quality within a small subbasin at the headwaters of Gates Brook prior to sewer construction. Sewers are now in the ground and many of the homes in the area have been connected. Improvements in water quality are expected. Additional areas in the watershed that have recently been sewered will also be examined to see if improvements can be detected.

Additional sampling recommended in the two previously published Environmental Quality Assessment Reports (Reservoir, Thomas Basin) will be done during 2003, as will special sampling to support the Quinapoxet Environmental Quality Assessment which should be completed by early 2004.